INSIDE! Pullout star charts

THE BRIGHTEST supernova in 400 years changed astrophysics p. 26

October 2007

Astronomy®

The world's best-selling astronomy magazine

How the BIG BANG forged the first elements

Echoes from the first minutes have changed scientists' minds about cosmic origins p. 32

OBSERVE AUTUMN'S BEST NEBULAE p. 58

SEE MARS IN HIGH DEF p. 54

Family ties reveal asteroid origins p. 38

Stargazing in New York City! p. 52

Equipment reviews p. 70 & p. 74

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Fusion in the universe's first few minutes created the lightest elements. A billion years later, stars filled out the rest of the periodic table.

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This side-by-side comparison tells the tale. Two images, one camera, one night, and no image processing*. Two very different results. Just look at the magnified view from the Schmidt-Cassegrain on the left. Notice the crescent-shaped distortion of the star images caused by coma. Now look at the magnified image of the same stars from the LX200R Advanced Ritchey-Chrétien** system and you will immediately see advantages of the ARC optical system. Sharp, round stars without coma. Sharp from the center all the way to the edge of this wide field.

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*The camera was a Canon 5D Digital SLR with a full 35 mm sensor. All of the above comparisons were taken using the original full frame images without any processing. The above images of M44 were taken by Jack Newton. See for yourself by downloading the two images and viewing them at 100% screen resolution from Meade.com.
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ASTRONOMY: ROEN KELLY

ON THE COVER

CENTER SECTION

26 Supernova 1987A: 20 years later

32 How the Big Bang forged the first elements

58 Observe autumn's best nebulae

54 Mars in high def

38 Family ties reveal asteroid origins

52 "Come see the Moon!"

70 Sky-testing William Optics' new refractors

74 Experience Meade's new eyepieces

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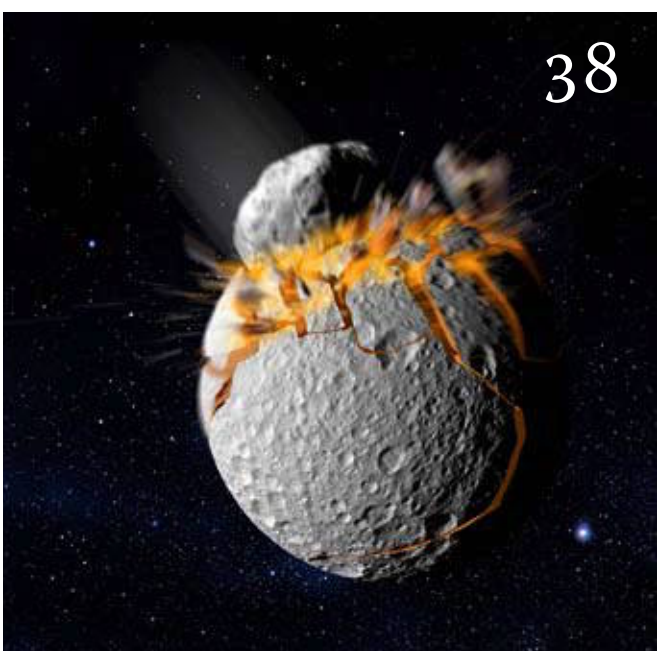


DANIEL D. DURDA (SWRI)

Astronomy

VOL. 35, NO. 10

The world's best-selling astronomy magazine

october 2007

06 **This month in *Astronomy***
The Big Bang and the elements

08 **Letters**

10 **Bob Berman's strange universe**
The real twilight zone

12 **Glenn Chaple's observing basics**
Happy birthday to the first satellite

14 **Phil Harrington's binocular universe**
Spying the sky's wet quarter
ONLINE EXTRA: Swim with some stellar gems in Aquarius.

16 **Stephen James O'Meara's secret sky**
Seven wonders

20 **Astro news**
Mars Express finds odd features, and more

26 **Supernova 1987A: 20 years later**
The brightest supernova since the telescope's invention taught astronomers a great deal about exploding stars — and points out a lot they still don't know. **RICHARD TALCOTT**
ONLINE EXTRA: Where's the neutron star the explosion left behind?

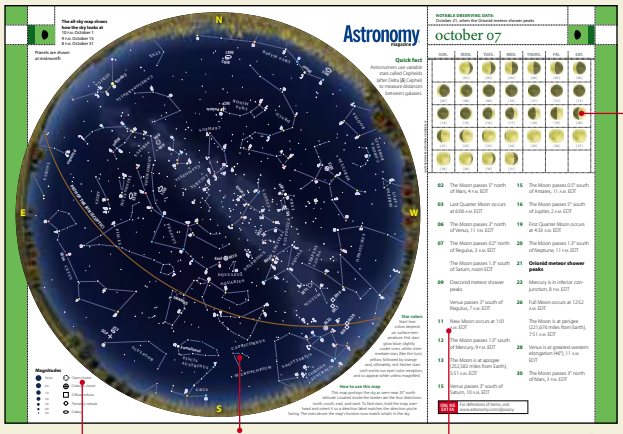
32 COVER STORY

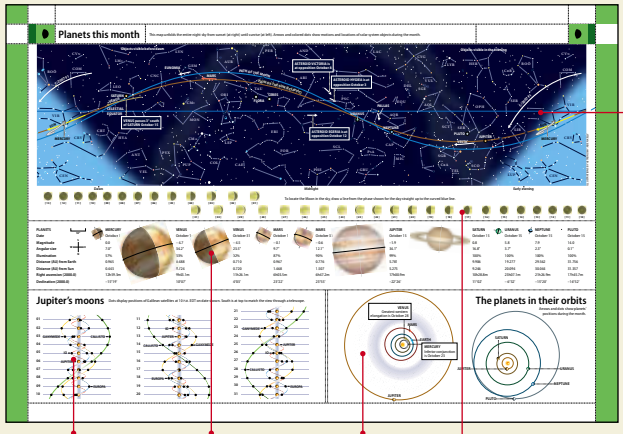
How the Big Bang forged the first elements
Nuclear reactions in the universe's first minutes made the lightest elements. This find changed scientists' minds about cosmic origins. **ADAM FRANK**
ONLINE EXTRA: Scientists predicted the cosmic microwave background.

38 **Family ties reveal asteroid origins**
Tracing the history of space rocks uncovers a cluster with a common origin. **DANIEL D. DURDA**
ONLINE EXTRA: Find out more about space weathering.

44 **The sky this month**
Planet action moves to the morning sky
MARTIN RATCLIFFE AND ALISTER LING

EXCLUSIVE PULLOUT STAR CHARTS: Your guides for observing this month's night sky (p. 44)





52 **"Come see the Moon !"**
One night, sidewalk astronomer Jeffrey Jacobs offered the Moon. But would skeptical New Yorkers accept the gift? **PHIL SCOTT**
ONLINE EXTRA: City skies hold more targets than just the Moon.

54 **Illustrated: Mars in high def**
The Red Planet explodes with detail under Mars Reconnaissance Orbiter's amazing cameras. **RICHARD TALCOTT**

58 **Observe autumn's best nebulae**
Intricate gas clouds and sparkling stars await you. **RICHARD JAKIEL**
ONLINE EXTRA: Download a Meade Autostar tour of these nebulae.

62 **Ask Astro**
- Will Pluto ever collide with Neptune or Uranus?
- How do astronomers measure stellar wind?
- What is a comet?
- What is a solar prominence?

66 **Astronomy thrives in Texas**
Find your astronomical adventure in the Lone Star state. **ROBERT REEVES**

70 **Sky-testing William Optics' new refractors**
Sharp optics in two beautiful packages make these telescopes easy to look at and easier to look through. **RAYMOND SHUBINSKI**

74 **Experience Meade's new eyepieces**
Choosing the right eyepiece is easy with Meade's Series 5000 oculars. **MIKE D. REYNOLDS**

78 **New products**

80 **Coming events**

81 **Advertiser index**

86 **Reader gallery**

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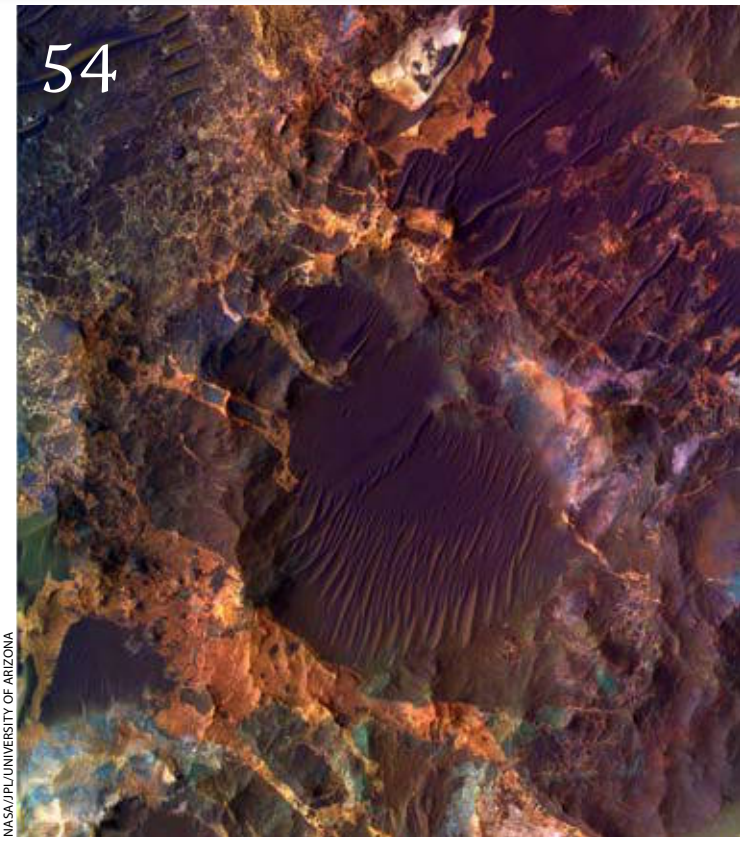

NASA/JPL/UNIVERSITY OF ARIZONA

WOLFGANG PROMPER

BY DAVID J. EICHER

The Big Bang and the elements

I think a good deal of what captivates us about cosmology comes from its ability to look back to moments in the cosmos we'll never see. The origin of the universe — the Big Bang — endlessly fascinates us as we grapple with the physics of unimaginable forces. The paradox of all the energy we'll ever know exploding apart and combining into what later became billions of galaxies, stars, planets, cosmic dust and — yes, even us — leaves us with a mind-numbing tingle.

Adam Frank's story "How the Big Bang forged the first elements" (p. 32) takes on one of these magic eras. In the first minutes after the Big Bang, nuclear reactions created the cosmos' lightest elements. Frank, a member of *Astronomy*'s editorial advisory board and an astrophysicist at the University of Rochester, takes us through this process of element creation that defined the universe to come — a process astronomers call Big Bang nucleosynthesis.

This field of astrophysics, known as "BBN," relies on a strong link between observed abundances of chemical elements and theoretical predictions based on Big Bang theory. "By going back only to about 0.01 second after the beginning, physicists limit themselves to a temperature and density domain they can work with comfortably," Frank writes. "Running the clock forward from 0.01 second, BBN can describe the universe's next 3 minutes in astonishing detail."

And those 3 minutes were key in establishing the universe that would follow. Sixty years ago, physicists Ralph Alpher, Hans Bethe, and George Gamow combined to describe how elements originated. (Thus, the celebrated 1948 paper in *The Physical Review* by Alpher, Bethe, and Gamow that would lead to jokes invoking the Greek alphabet ever since.) Astronomers have learned a vast amount about nucleosynthesis since those days, and Frank's article neatly summarizes the current state of precision cosmology. I suggest it is a read worthy of your valuable time.

This issue contains another timely science story: Senior Editor Richard Talcott's recounting of the tale of Supernova 1987A. Twenty years ago, this star exploded in the Large Magellanic Cloud and forever changed what astronomers know about supernovae and a whole lot more. In "Supernova 1987A: 20 years later" (p. 26), Talcott tells what this star taught us about how stars explode, and the surprising information astronomers are still gaining from the supernova.

On a staffing note, I'd like you to join me in welcoming Erin Dolan as our editorial intern. Erin is a senior majoring in print journalism, visual communications, and Catholic studies at the University of St. Thomas in St. Paul, Minnesota. She lives in Brookfield, Wisconsin, and enjoys painting, writing, and traveling.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 35, Number 10

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Advertising Sales Representatives
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How to avoid a suntan

Richard Talcott's "Earth's deadly future" (July 2007) was a very good article. Recent work by Don Korycansky at UC-Santa Cruz, Fred Adams at the University of Michigan, and other researchers at NASA indicates Earth's fate may not be as dire as it seems.

It might be possible to slowly nudge Earth into an orbit that takes it farther from the Sun, at a rate that compensates for the increased solar-energy output.

This could be done by adjusting an asteroid's orbit, making the space rock repeatedly pass near Earth's orbit with precisely the right period and distance to affect Earth's orbit properly. **— MIKE MORTENSON,** PORT TOWNSEND, WASHINGTON

Great new videos

As a new *Astronomy* subscriber and an avid reader of your web site, I think the product showcase videos are terrific.

They are informative and very useful. Please use this format for many more products. **— LARRY O'MAHONEY,** NEW ORLEANS

I think your videos are a great addition to your web site. I can't wait until new ones come out.

I also like that you put page numbers on the front of the magazine. That makes your articles easy to find. **— ROD SUTTER,** PHOENIX

Check out our new videos at Astronomy.com/videos.

Celestial geometry

In "The sky this month" (May 2007), two graphics show the eastern elongations of Venus (page 44) and Mercury (page 50). In both of them, the point of the elongation is not at the uppermost point relative to the horizon after sunset.

Why is the highest point not the greatest elongation? Isn't the elongation when the planet is farthest from the Sun, as we see it? **— RICHARD ALLEN,** SCOTTSDALE, ARIZONA

This would be true if Earth's axis didn't angle to its orbit. Because it does, the ecliptic — the plane of Earth's orbit around the Sun, and the apparent path of planets in the sky — cuts the horizon at a different angle at different times of year.

Astronomers measure planetary elongation from the Sun along the ecliptic. For observers in the Northern Hemisphere, the best evening apparitions always occur when Mercury and Venus have greatest eastern elongations near the March equinox. This is when the ecliptic cuts the horizon most steeply.

Likewise, morning apparitions are best when greatest western elongations occur near the September equinox. (Flip these rules for observing in the Southern Hemisphere.) **— FRANCIS REDDY,** ASSOCIATE EDITOR

WHEN THE SUN becomes a red giant in 5 billion years, its bloated atmosphere will consume Earth — unless we can move the planet. SOHO (ESA/NASA)

Correction

The article "The ugly side of gravity" (August 2007) said "Earth and Moon are tidally locked." In fact, the Moon is tidally locked to Earth. **— *ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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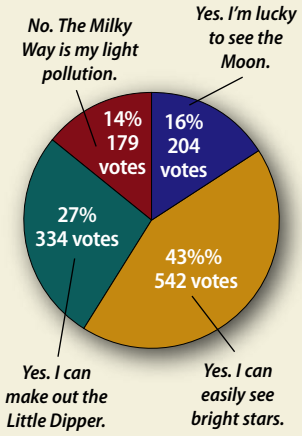
POLL QUESTION:

Is light pollution an issue where you live?


No. The Milky Way is my light pollution.
Yes. I'm lucky to see the Moon.
14% 179 votes
16% 204 votes
27% 334 votes
43%% 542 votes
Yes. I can make out the Little Dipper.
Yes. I can easily see bright stars.

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The Rosette Nebula dual frame mosaic image taken with Tele Vue-NP127is and Apogee Alta U9000 CCD camera by Tim Puckett and Adam Block.

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BY BOB BERMAN

The real twilight zone

Rod Serlings' classic television show

The Twilight Zone would have bombed on Pluto. In fact, visiting aliens from any known planet would be amazed by the unique twilight we earthlings take for granted. Only here is day's transition to darkness a colorful affair. ☾ Throughout most of the solar system, the Sun sets and — wham! — like a power failure, there's instant blackness. In our neck of the woods, Mars almost succeeds, but its thin air can't produce a palette of saturated colors. That leaves us to ponder the phenomenon, along with bats and other crepuscular characters that cleverly avoid both day and night predators.

"Crepuscular" is a wonderful word that means "pertaining to twilight." It can describe Mercury, mosquitoes, or those fantasyland beams streaming out of the sunset, called "crepuscular rays." It has such a great sound, I say "crepuscular" as often as possible, even when it's inappropriate.

The fun starts with the Sun balanced atop the horizon, where its rays traverse 13 times more air than when it's high up. This causes nearly all of its blue light to scatter out, leaving only the longer wavelengths. That's why the setting Sun is orange. Even rainbows just before sunset have little or no blue.

Next, the Sun's disk transits the horizon, which takes 2 minutes in the tropics and 3 for nearly everyone else, thanks to its angled path in temperate countries.

Then comes twilight, which sounds vague, but is actually very precisely defined. And there's really not one, but three.

Civil twilight begins at sunset and is the period of intense colors. Rayleigh scattering of solar wavelengths through the variety of low air thicknesses near the skyline causes these colors. Civil twilight officially ends when the Sun has plunged 6° below the horizon, equal to 12 times its own width. That's when streetlights must be on, according to most municipal ordinances.

Nautical twilight persists longer, until the Sun is 12° down. That's when a mariner can't distinguish between sea and sky. Colors are now gone.

Astronomical twilight continues still longer, until the Sun falls 18° below the horizon, letting the faintest stars emerge. Its conclusion heralds the arrival of full darkness, when toes stub and scopes swing toward galaxies.

Twilight's duration is expressed in degrees instead of time for good reason: Its length varies. Depending on the season and latitude, civil twilight can expire in less than half an hour or linger through the night. It's always shortest in the tropics, where 24 minutes is typical. A shame: Swaying palms go nicely with twilight's mild air and vivid colors. From Seattle, civil twilight averages about 36 minutes. In Fairbanks, Alaska, it's a full hour around now, and it simply never ends after sunsets between mid-May and the end of July. Those arriving then and hoping to see aurorae are wasting their time.

> REAL TWILIGHT, fortunately, is far from extinct, and it plays host to marvels not seen any other time.

Thanks to twilight's slow pace, we rarely sense how dim the light has become. Photochemical changes in the eyes, pupil dilation from 2.5 to nearly 7mm, and the shift to scotopic rod-cell vision make the transition so smooth, we'd never guess that ambient illumination during early astronomical twilight has grown 500,000 times dimmer than when the Sun was shining. In modern times, of course, artificial lights have modified the passage to night. Urban eyes rarely experience full darkness. Major cities offer constant illumination resembling midnautical twilight, and the Milky Way has long been reduced to a staged curiosity that draws appreciative gasps at planetaria.

Real twilight, fortunately, is far from extinct, and it plays host to marvels not seen any other time. The most reliable spectacle of civil twilight is the twilight wedge — Earth's shadow as a striking gray-blue band atop the eastern horizon just after sunset. Other goodies include crepuscular rays, antisolar rays — which converge just above the horizon opposite the newly vanished Sun — and the appearance of Venus and Mercury.

Nautical twilight is the realm of emerging Earth satellites and the brighter stars. Finally, the darkest part of astronomical twilight is when the legendary zodiacal light lights up the ecliptic near the horizon. Its eerie glow is widest at the bottom, narrowest on top. This month, the zodiacal light is best seen before dawn in the Northern Hemisphere, and after sunset in the southern.

In morning twilight, we're presented with a wonderful chance to glimpse Mercury, whose best before-dawn appearance of 2007 begins the last days of October and continues for 3 weeks. Morning twilight is also now home to Venus, which in early October shines at its brightest of the year at magnitude –4.5. Count on numerous UFO reports by sleepy characters in the wee hours misidentifying Venus, which won't be this conspicuous again until 2015.

They'll think they've seen something from the twilight zone. And they'll be right.

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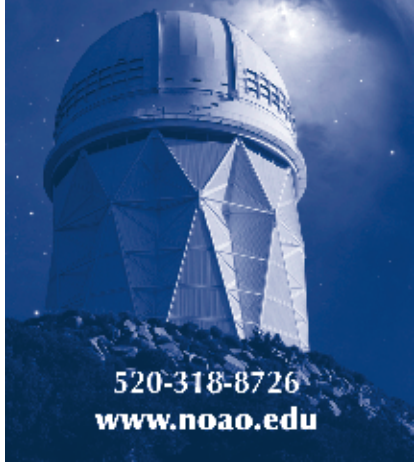

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BY GLENN CHAPLE

Happy birthday to the first satellite

On October 4, 1957, the Soviet Union launched Sputnik I, the world's first artificial satellite. For the first time in history, earthlings could gaze upward and see a man-made object drifting serenely among the stars. A few months later, the United States sent Explorer I into orbit. With this, satellite-watching became a popular pastime. Hundreds of people, many of them amateur astronomers, tracked the positions of these early satellites. Under the aegis of Project Moonwatch, these dedicated volunteers relayed their information by telephone and postcards to the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. The data enabled scientists to deduce orbital elements for the satellites.

By the mid-1960s, tracking stations reduced the need for amateurs' observations of orbiting spacecraft. Satellite-spotting lost favor with skywatchers and achieved nuisance status with astrophotographers. The bright trails left by passing satellites "spoiled" countless long-exposure space photos.

Fifty years after Sputnik's launch, satellites have become old hat. Today, a handful of man-made orbiting objects still command observers' attention. The space shuttles and International Space Station (ISS) interest us because we know humans are on board. Occasionally as bright as Jupiter, the shuttles and ISS are impressive sights as they streak across the sky. Brighter yet are Iridium satellites — part of an ill-fated communications project — whose dazzlingly bright "flashes" can be as bright as magnitude –8! The Hubble Space Telescope piques our interest because of its celebrated status.

When is the best time to view satellites? Try observing typical satellites, depending on their orbital heights, an hour or so after sunset or before sunrise. That's because artificial satellites shine the same way our Moon does: reflected sunlight. Just as a mountain's peak remains sunlit after the valley below has fallen into darkness, so a high-orbiting satellite captures sunlight well after sunset. Typical satellites appear as moving "stars," but some brighten and fade as their tumbling motion exposes surfaces of varying reflectivity. If it's following a west-to-east track, the satellite will quickly enter Earth's shadow and disappear from view.

THE INTERNATIONAL SPACE STATION flies over the launch pad at Kennedy Space Center in Florida the night before space shuttle Atlantis launched for STS-115. BEN COOPER/WWW.LAUNCHPHOTOGRAPHY.COM

To learn more about satellite observing, I recommend two web sites. Canadian skywatcher Kevin Fetter alerted me to the first: www.satobs.org. This site includes beginners' tips and information on reentering satellites.

Also visit www.heavens-above.com. This free service provides nightly data on a variety of satellites above your area. I recently searched for man-made objects brighter than magnitude 4.5. I received a list that included nearly 40 satellites and booster rockets — all visible within an hour after sunset that night.

Data on the passage of a particular satellite include azimuth and altitude when first visible, at greatest height above the horizon, and at disappearance. The azimuth is the horizon compass point closest to the satellite and is measured from north (0°) around to the east (90°), and so on. The angular distance from the satellite to the nearest point on the horizon is its altitude, measured from the horizon (0°) to the zenith (90°). You can estimate angular degrees with your outstretched hand. A closed fist is about 10° across, while the thumb and little finger extended out and to the sides span approximately 25°.

One of my most memorable man-made object observations involved ISS. Last December, I observed from an open field adjacent to the middle school where I teach. Then, the space station played host to astronaut Sunita Williams. Months earlier, she had visited our school and told the students about the space program. It was hard to believe that someone who had walked those corridors was now "up there," streaking around Earth every 90 minutes.

If you gaze at an ISS flyby or the "flash" of an Iridium satellite this month, take a moment to wish a happy 50th birthday to the satellite that started it all.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com.

Next month: A visit to the first asteroid.

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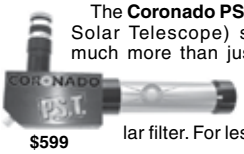

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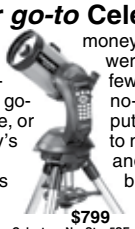
The **Astro-Tech** *dielectric* 1.25" star diagonal is a *Sky & Telescope Hot Product for 2007*. It has 99% reflectivity *46-layer* dielectric mirror coatings. Its compression ring eyepiece holder won't scratch eyepieces. At only $69.95, it certainly *is* a best buy. And it's one of *five* great-value dielectric diagonals from Astro-Tech.

When we opened in 1979, a Celestron 8 cost $1295. Today, an even better *go-to* Celestron 8 is only $1399.



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Celestron NexStar 5SE 5" Schmidt-Cassegrain

The best 1979 Celestron C8, which we sold back then for $1295, would cost $3709.28 in today's inflated dollars – but wouldn't have the go-to computer, multicoatings, DC drive, or quality Plössl eyepiece of today's $1399 **Celestron NexStar 8 SE.**

But it *would* still have Celestron's superb Schmidt-Cassegrain optics. That's one important benefit for you that hasn't changed over the years.

When you think about it, a Celestron's cost has actually *deflated* over the years. You get more telescope, but you pay less money, because many of today's features were unavailable at *any* price only a few short years ago. Features like the no-guesswork *SkyAlign* go-to computer that finds objects automatically to make astronomy as easy as 1-2-3, and Starbright XLT multicoatings for brighter images and higher contrast.

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TMB-80CF carbon fiber triplet apo **$1395**

TMB-80 triplet apo **$995**

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The **TMB-80CF**, above left, puts TMB-80 triplet FPL-53 apochromatic optics in a unique, lightweight, and incredibly strong high tech carbon fiber body. As a crowning touch, it adds a famous *FeatherTouch* 2.5" dual-speed Crayford focuser.

The very compact 92mm f/5.5 **TMB-92** triplet apo below fills the void left by the discontinued 90mm Astro-Physics Stowaway (a legendary scope that sells for up to $6000 on the used market). But you won't pay $6000 for the new TMB-92. This fast focal ratio 92mm TMB apo is only $1999. The TMB-92 has a collimatable lens cells and a famous *FeatherTouch* 2.7" dual-speed rotating rack and pinion focuser.

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BY PHIL HARRINGTON

Spying the sky's wet quarter

The southern sky, dominated by Milky

Way star clouds in Scorpius and Sagittarius just a month ago, now appears empty and barren. Now, we find Capricornus and Aquarius. ☾ Neither constellation is easy to see, but both hold several interesting targets visible through binoculars.

Let's start with Capricornus the Sea-Goat. This triangular constellation's origin is lost to history, but depictions of a half-goat/half-fish have been found on Babylonian tablets dating back more than 3,000 years.

In the Capricornus triangle's western corner, you will find not just one, but two pretty sets of double stars in the same binocular field. **Algedi** (Alpha [α] Capricorni) comprises two 4th-magnitude stars easily seen even through 8x21 pocket binoculars. Surprisingly, Algedi's stars are nowhere near each other. The western star, Alpha[1], is 690 light-years from us, while Alpha[2] is 109.

Dabih (Beta [β] Capricorni) is south of Algedi. Although Alpha[1] and Alpha[2] are nearly the same brightness, Dabih's two stars are strikingly different. Dabih Major, as it is called, shines at magnitude 3, while its companion, Dabih Minor, is only 6th magnitude. We also know the Dabih system includes at least three other stars that go unseen through our binoculars, so this is a quintuple-star family.

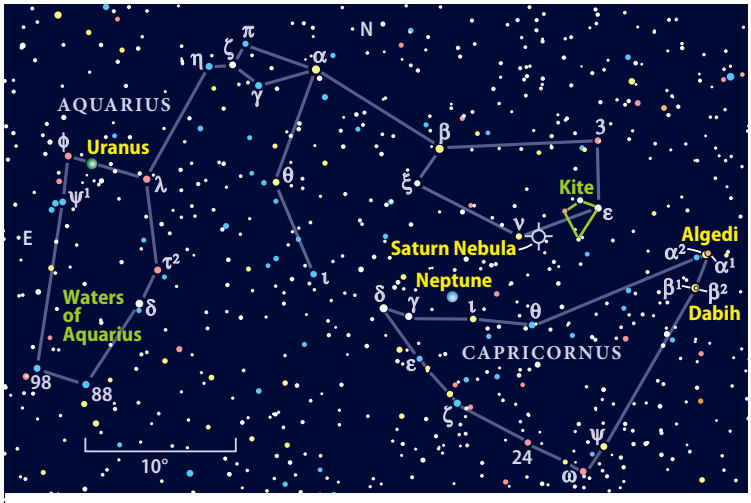
Capricornus currently hosts **Neptune**, just as it did when German astronomer Johann Galle discovered the planet September 23, 1846. Since its discovery, Neptune has marched slowly around the sky, having yet to complete a full orbit. Although Neptune glows at only magnitude 8, binoculars as small as 7x35 will reveal it. To find Neptune, trace the top of Capricornus' triangle eastward from Algedi and Dabih to the stars Theta (θ) Capricorni, Iota (ι) Capricorni, Nashira (Gamma [γ] Capricorni), and Deneb Algiedi (Delta [δ] Capricorni). Neptune's pale turquoise dot lies northwest of the halfway point between Iota and Nashira.

Uranus lies to the east-northeast of Neptune across the border in Aquarius. While spotting Neptune can be a little daunting in binoculars, 6th-magnitude Uranus is easier. Find it two-thirds of the way between 4th-magnitude Lambda (λ) Aquarii and Phi (φ) Aquarii. Uranus' greenish color will set it apart from surrounding field stars.

One year after William Herschel discovered Uranus in 1781, he stumbled upon a small greenish object in Aquarius. At first, Herschel thought he had found another planet. After the object failed to move against the background stars, however, he concluded that his new object was not orbiting the Sun and had to lie beyond our solar system. Owing to its similar appearance to Uranus through his telescope, Herschel coined the term "planetary nebula."

Today, we know Herschel's discovery as NGC 7009 — nicknamed the **Saturn Nebula** for its telescopic likeness to the ringed planet. To find the Saturn Nebula, look northeast of Algedi for three stars that form a slender triangle. Add in a fourth, fainter star to their south to create a kite-shaped asterism. NGC 7009 looks like a faint, pale, greenish "star" east of the kite. It's a tough catch, however, so be sure you steadily brace your binoculars.

Next month, we'll play a late-season round of golf. Until then, remember that two eyes are better than one! ✦



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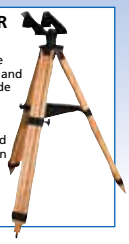

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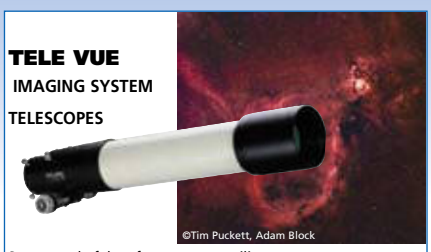

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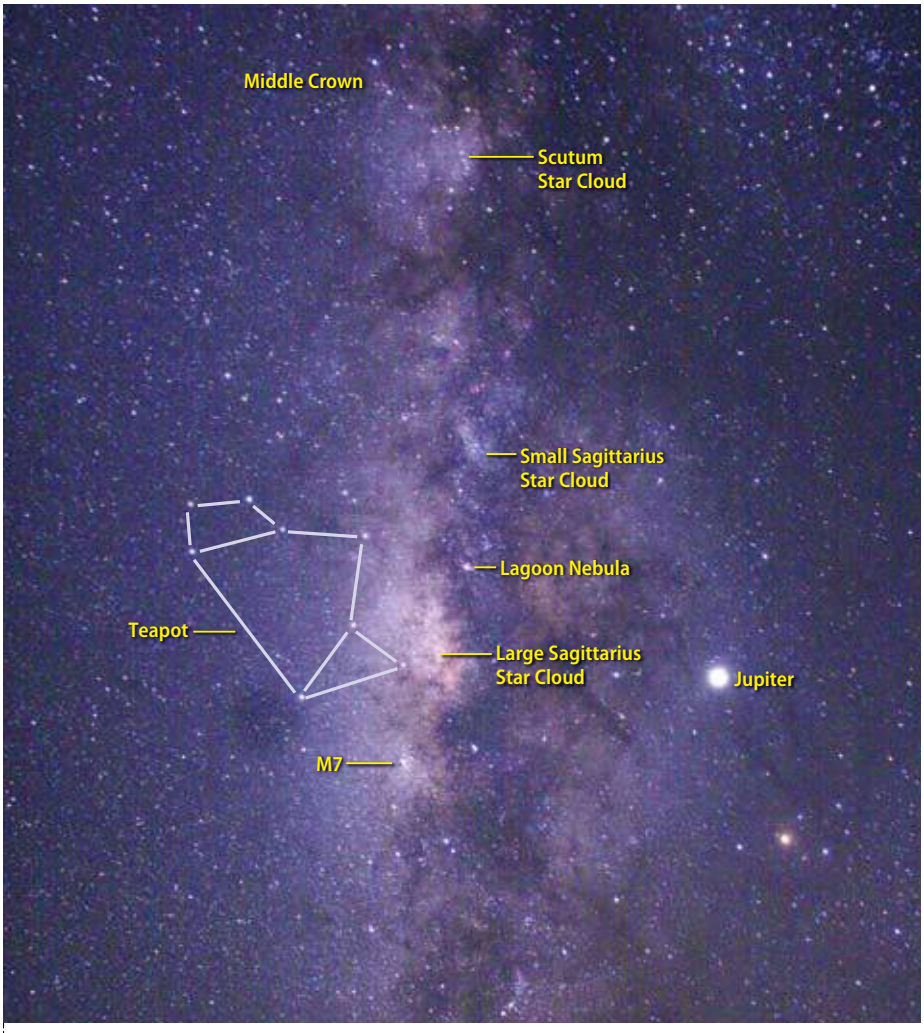
BY STEPHEN JAMES O'MEARA

Seven wonders

This fall, go outside as soon as the sky turns dark and look due south. The marbled motif of summer's Milky Way is rising nearly vertically into the heavens. This vista of hazy starlight makes its biggest splash around the hub of our galaxy, between Scorpius' "stinger stars" and Sagittarius' Teapot asterism. The Milky Way then courses high overhead, where it ripples through Cygnus. Each year, from July to mid-October, we can enjoy this swell, and relish what I call "The seven wonders of the summer Milky Way" — all majestic, naked-eye structures larger than the Full Moon and inspiring to a roaming eye under a clear, dark sky. Grab this opportunity while you can, because, by October's end, Scorpius will have slipped below the horizon.



OPEN CLUSTER M7 marks the starting line for your naked-eye observational tour of the Milky Way. If we could magically relocate this feature into a star-poor region of the sky, it would rival the Pleiades star cluster (M45) in Taurus in size and splendor. STEPHEN JAMES O'MEARA

Magnificent seven

Working from south to north, our first wonder is the glorious open star cluster **M7** (NGC 6475) and its surrounding star cloud. While M7 is bright enough (3rd magnitude), and large enough (75'), to stand alone as a "nebulous" naked-eye wonder, its glory is enhanced by a bright patch of distant Milky Way. The cloud appears to extend the cluster's borders by nearly a factor of two and magnify its brilliance. Seen together, the cluster and cloud look like the blazing head of a comet with a bright core (M7) and diffuse outer coma.

The **Large Sagittarius Star Cloud** is nature's 5° by 7° portrait of galactic wonder. Just look about 10° north-northeast of M7 for a spectacular swath of milky madness. This cloud marks the true heart of the Milky Way. Longfellow might have been looking at this region when he penned the opening lines to his poem "The Galaxy": Torrent of light and river of the air, / Along whose bed the glimmering stars are seen / Like gold and silver sands in some ravine.

Indeed, careful observers have seen this cloud glow with a pale golden sheen, which contrasts well with the neighboring strands of silver starlight. Both these hues are distinct in color photographs — the real and awesome result of us looking some 30,000 light-years across the dusty plane of our galaxy toward its center.

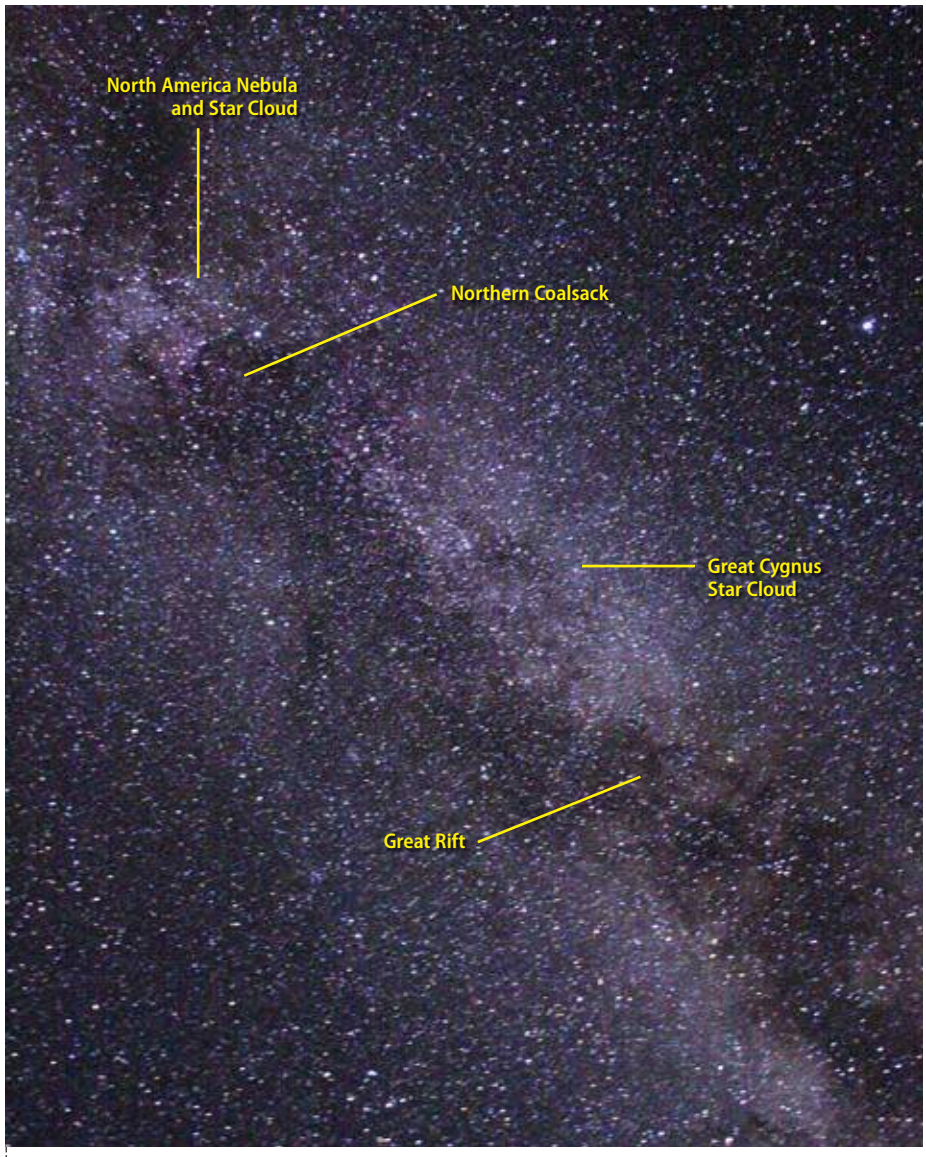
Jump the ravine containing the Large Sagittarius Star Cloud and dive into the **Lagoon Nebula** (M8). There's no mistaking this concentrated 3rd-magnitude glow, which appears as an isolated curdle of

"milk" 5° west and slightly north of 2nd-magnitude Lambda (λ) Sagittarii (the star marking the Teapot's tip). M8 is one of the heavens' brightest combinations of a diffuse nebula and cluster.

Spanning 90' by 40' of sky, the nebulosity can be seen without optical aid, like a stain of cold breath on glass. But the object's true visual punch comes from two close naked-eye stars coupled with the light from the 5th-magnitude open star cluster NGC 6523, all of which follow the nebula's major axis. The M8 complex is a dynasty of galactic splendor — a site where new stars arise from dusty molecular clouds spread across more than 130 light-years of space, all seen 5,000 light-years distant.

The **Small Sagittarius Star Cloud** (M24) is a vast citadel of scintillating starlight nearly 10,000 light-years away. To the unaided eye, the 1.5° rectangular glow looks like a flying carpet on the fringes of the galaxy's center. Like the Large Sagittarius Star Cloud, M24's isolated appearance is an optical illusion caused by the framing of chance dark dust lanes in our line of sight. Sweep these dusty cobwebs away, and we'd see the Small and Large Sagittarius star clouds blend and bloom into a garden of delight. If you compare the colors of the two clouds, you might see a distinct difference — M24 has a subtle, polished emerald hue — the color becomes most distinct through binoculars and rich-field telescopes.

American astronomer E. E. Barnard called the **Scutum Star Cloud** the "Gem of the Milky Way" — a grand ghost of sepulchral light, like St. Elmo's fire clinging to a ship's broad sail. The cloud's brightest segment lies between 4th-magnitude Beta (β) Scuti and 5th-magnitude Epsilon (ε) Scuti. This is between the southwestern rim of what I call the Middle Crown — 14, 15, Lambda (λ), and 12 Aquilae and Eta (η) and Beta Scuti — and the Scutum Trapezoid, which includes the stars Alpha (α), Delta (δ), and Epsilon Scuti. The "Gem" is bordered to the north by a dark arc of dust known as Barnard 320, which looks like an ink stain on a blotter. With averted vision, the cloud becomes the bright northwestern segment of a larger crescent of milky wonder, which curves another 3° to the south via the east.



CYGNUS HOLDS the final two wonders of the summer Milky Way. Although the tour began with the brilliance of gleaming stars, for O'Meara, the Northern Coalsack and Great Rift hydrogen gas clouds are celestial metaphors for death and despair. STEPHEN JAMES O'MEARA

We end our tour with the **Northern Coalsack** and the **Great Rift** in Cygnus — two deliciously dark treats melded into one. The Northern Coalsack is a giant (8° by 5°) ellipse of dust between Alpha (α), Gamma (γ), and Epsilon (ε) Cygni. A bright star cloud containing the North America Nebula borders it to the northeast, while the magnificent Great Cygnus Star Cloud rams into it from the southwest. That latter shoal of light officially separates the Northern Coalsack from the headwaters of the Great Rift — a fantastic dust belt that divides the Milky Way into two parallel streams from Cygnus to Centaurus.

If the Large Sagittarius Star Cloud is the Milky Way's poetic soul, then the Northern Coalsack and the Great Rift represent the darkness of human terror and imagination. Ancients regarded these dusty coalsacks as mysterious, fear-invoking voids. Today, we know they are gas clouds that cloak or dim the light of whatever lurks beyond them. Still, seeing these "deep," black pits silhouetted against the brilliant Milky Way mirrors our fear of death. Do you dare look?

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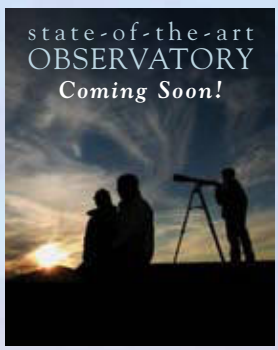

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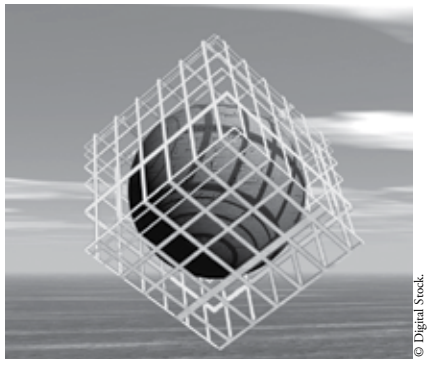
Professor Michael Starbird is a distinguished and highly popular teacher with an uncommon talent for making the wonders of mathematics clear to nonmathematicians. He is Professor of Mathematics and a Distinguished Teaching Professor at The University of Texas at Austin. Professor Starbird has won several teaching awards, most recently the 2007 Mathematical Association of America Deborah and Franklin Tepper Haimo National Award for Distinguished College or University Teaching of Mathematics, which is limited to three recipients annually from the 27,000 members of the MAA.



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7. Abstracting the Derivative—Circles and Belts
8. Circles, Pyramids, Cones, and Spheres
9. Archimedes and the Tractrix
10. The Integral and the Fundamental Theorem
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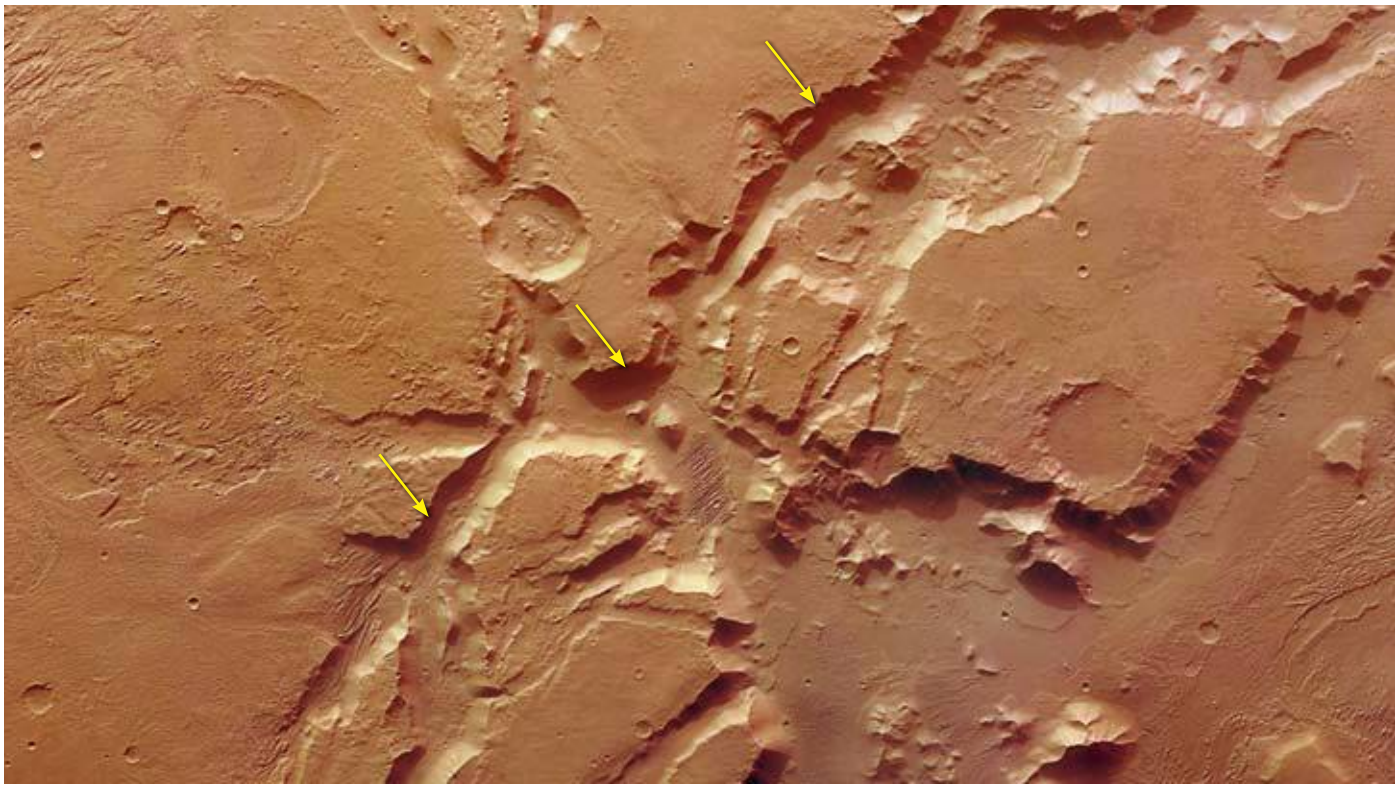

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AEOLIS MENSAE. **Wind-sculpted terrain and strange linear features characterize this tectonic transition zone on Mars near the Elysium volcanic region. Sun shines across this composite image from the west (right).**

22 Hubble image is best of M81

23 SDSS reveals record optical Einstein ring

24 Sputnik-1 — a milestone in spaceflight

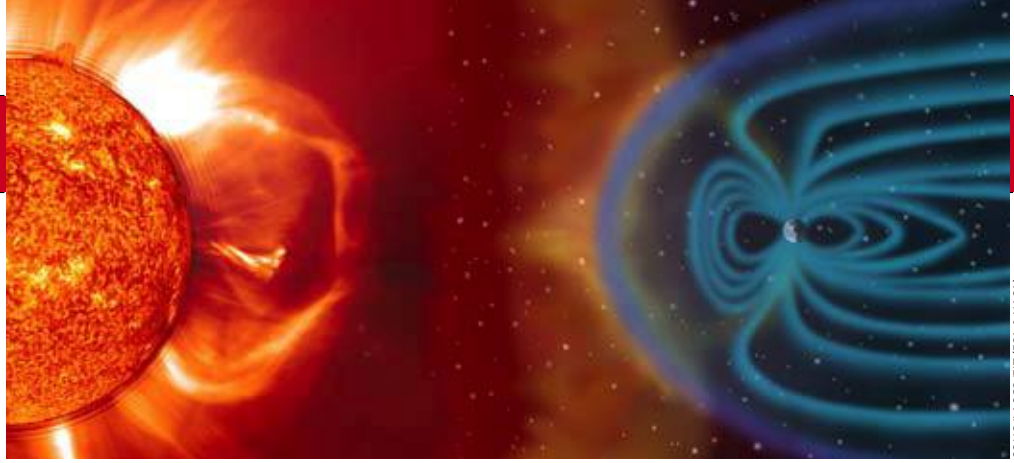
25 Dwarf-galaxy bonanza

Mars Express finds odd linear features on the Red Planet

The High Resolution Stereo Camera (HRSC) aboard Mars Express imaged long, straight cracks on the border between Mars' northern plains and southern highlands in the Aeolis Mensae region. The European Space Agency presented the images June 28.

This composite image of Aeolis Mensae shows a region located at 6° south and 145° east. In the transition zone, also called the "global crustal dichotomy boundary," elevation changes some 1.9 miles (3 kilometers) between the low-lying plains to the north and the southern highlands. The terrain in the Aeolis Mensae region appears windblown and fractured, with 1.6-mile-deep (2.5 km) valleys and long, trench-like structures.

Linear features found on valley floors perplex scientists. They suspect glacial processes formed the grooves, but these trench-like structures lie at right angles to the lengths of the valleys, which suggests wind erosion played a part in their formation. For now, what process formed these strange, linear structures remains unknown. — **LAURA LAYTON**



SOHO/LASCO/EIT (ESA & NASA)

GAS BLAST. A coronal mass ejection (CME) blasts off the Sun's surface in this illustration. The gas blob strike's Earth's magnetic cocoon a few days later. CMEs can trigger dangerous radiation storms in space.

Coronal mass ejection warnings possible

A new discovery could provide warnings of impending coronal mass ejections (CMEs). During such events, billion-ton blobs of super hot gas erupt from the Sun, triggering radiation storms near Earth. The CMEs damage satellites and may expose astronauts to dangerous doses of radiation.

A team of American and French scientists made the discovery. Team member Natchimuthuk Gopalswamy of NASA's Goddard Space Flight Center in Greenbelt, Maryland, explained the development May 29 at the American Astronomical Society conference in Honolulu. Gopalswamy and his colleagues found a way to use the Solar and Heliospheric Observatory (SOHO) and Wind, another Sun-watching satellite, to identify storm-stirring CMEs.

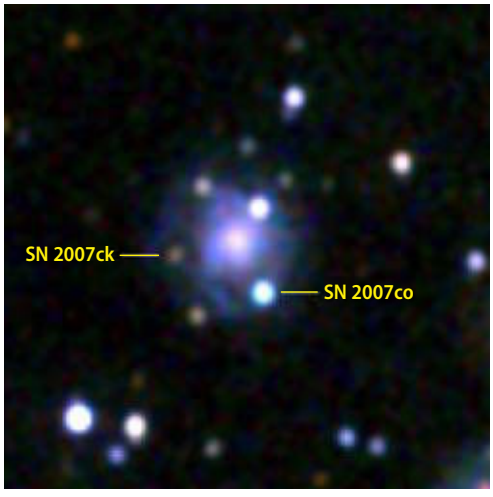
The scientists scrutinized 472 CMEs from 1996 to 2005. As CMEs move through space, they plow through the solar wind — a stream of charged particles emanating from the Sun. Some CMEs accelerate atomic nuclei in the solar wind enough to produce radiation. They also boost electrons to high speeds, producing a distinctive radio "scream."

The scream travels at the speed of light, faster than the radiation-producing shock wave. Gopalswamy says that could provide "a few tens of minutes to a couple of hours" for astronauts and satellite operators to prepare. **— DANIEL PENDICK**

Two supernovae explode in same galaxy

Two supernovae exploded 16 days apart in a galaxy in the constellation Hercules. Astronomers using NASA's Swift satellite observed the stellar explosions in MCG +05-43–16, a galaxy 380 million light-years from Earth. This marks the first time scientists witnessed dual blasts in the same galaxy in such a short time. "Most galaxies have a supernova every 25 to 100 years," says Stefan Immler of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Scientists observed the first explosion, Supernova 2007ck, May 19. This type II event happens when a massive star's core collapses and the resulting shock wave obliterates the star. On June 4, they discovered Supernova 2007co, a type Ia supernova. This type of explosion occurs when a white-dwarf star steals material away from a companion star, gains mass, and then explodes. A white dwarf is an Earth-sized core left after a Sun-like star consumes its fuel and expels its atmosphere. The image is a composite of red, green, and blue frames captured June 9 and 12 with Swift's Ultraviolet/Optical Telescope.



STEFAN IMMLER (NASA/GSFC, SWIFT SCIENCE TEAM)

DUAL EXPLOSIONS. NASA's Swift satellite watched two supernovae explode in the same galaxy 16 days apart.

It's unusual for both supernova types to happen in the same galaxy at nearly the same time. However, the blasts were actually separated by tens of thousands of light-years. Astronomers will no doubt continue to watch what happens in this strange and chaotic galaxy. **— L. L.**

QUICK TAKES

OFFICE OF THE EXOTIC
NASA announced in June it has created the Einstein Probes Office to support missions to study exotic phenomena like black holes.

MAMMOTH IMPACT
The woolly mammoth may have disappeared 10,000 years ago due to a comet impact, says a team of scientists. Richard Firestone of Lawrence Berkeley National Laboratory presented the findings May 21 at the American Geophysical Union meeting.

JANSKY AWARDEE NAMED
German astronomer Karl Menten of the Max Planck Institute in Bonn, Germany, received the 2007 Karl G. Jansky Lectureship award.

FASTER WAVES
Ocean waves spanning hundreds of kilometers from peak to peak are speeding up because of ocean warming, say scientists at Canada's University of Victoria in British Columbia.

BACK TO THE FUTURE
During its June 8 flight to the International Space Station, space shuttle Atlantis carried a 400-year-old metal cargo tag inscribed with "Yames Towne." The tag commemorates the 400th anniversary of Jamestown, Virginia.

SURVEY SAYS . . .
A Zogby's Real America newsletter survey finds 30 percent of respondents are interested in space tourism.

CHINESE MILESTONE
China launched its 100th Long March booster May 31, placing a SinoSat-3 communication satellite into orbit.

INGREDIENTS FOR LIFE
On July 4, NASA's Cassini spacecraft detected hydrocarbons (the basic chemicals needed for life) on Saturn's moon Hyperion.

EXTENDED MISSIONS
In July, NASA extended Deep Impact's comet-observing mission and reassigned Stardust to look for exoplanets.

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NASA launches asteroid probe

NASA's Dawn spacecraft launched July 7. The craft is on its way to the asteroid belt — the region between Mars and Jupiter — to investigate two of its heftiest members, asteroid Vesta and dwarf-planet Ceres. The craft will orbit Vesta in 2011 and Ceres in 2015.

To prepare for Dawn's arrival, astronomers snapped images of Vesta May 14 and 16 using the Hubble Space Telescope's Wide Field Planetary Camera 2. The images reveal brightness differences in the east and west and a giant impact crater 285 miles (456 kilometers) across on the 330-mile-diameter (530 km) asteroid.

Previous Hubble images of Ceres also show bright and dark regions and large impact craters. Astronomers captured these images of Vesta and Ceres between December 2003 and January 2004 using Hubble's Advanced Camera for Surveys. Ceres is about 590 miles (950 km) across and spherical, suggesting a rocky, layered, terrestrial-planet composition.

Dawn's close-up views of Vesta and Ceres will help astronomers study the bodies' surface features and probe their interiors. — **L. L.**

VESTA UNVEILED. **NASA's Hubble Space Telescope Wide Field Planetary Camera 2 imaged asteroid Vesta in May.** NASA/ESA/ L. McFADDEN (UNIV. OF MARYLAND)

CERES' CLOSE-UP. **Hubble's Advanced Camera for Surveys imaged dwarf-planet Ceres January 24, 2004.** NASA/ESA/J. PARKER (SOUTHWEST RESEARCH INSTITUTE)

Hubble image is best of M81

NASA/ESA/THE HUBBLE HERITAGE TEAM

SPIRAL BEAUTY. **M81 in Ursa Major is one of the brightest galaxies seen from Earth. Its apparent magnitude of 6.8 is near the limit of naked-eye visibility.**

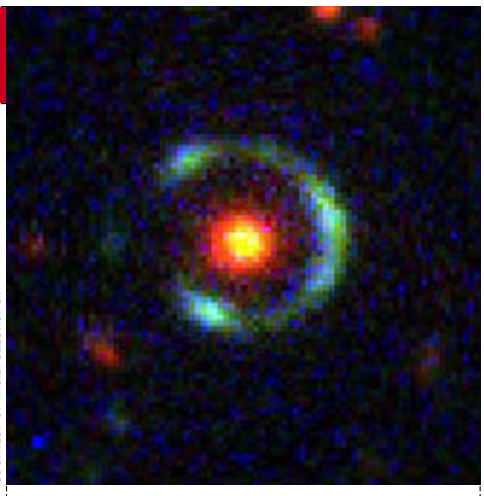
Astronomers released a new Hubble Space Telescope image of the galaxy M81 in Ursa Major at the June American Astronomical Society meeting in Honolulu. At a distance of 11.6 million light-years, M81 is one of the closest prominent spirals outside the Local Group of galaxies.

The image was made by a team of astronomers and presented at the meeting by Andreas Zezas of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. "The amazing detail in this image took our breath away," says Zezas. "We can see individual stars like tiny grains of sand."

The image is a composite of 90 pictures taken with Hubble's Advanced Camera for Surveys between 2004 and 2006. The picture contains about 2.5 days of total exposure time.

M81's spiral arms contain young, hot, blue stars that turned on in the last few million years. Slightly greenish regions in the image represent bright star-forming areas. Dust lanes wind their way along the galaxy's spiral arms, which "shows that star formation is happening all the way down into the nucleus," says Zezas.

Astronomers will study the new image to map the star-formation history of M81 and to correlate observations of black holes and neutron stars made with the Chandra X-ray Observatory. — **DAVID J. EICHER**



COURTESY OF VASILY BELOKUROV

LENSING GALAXY. **The Cosmic Horseshoe is a giant Einstein ring. The "lens" galaxy at the center is red and no longer forms new stars. But light from the more distant source galaxy is blue, indicating active star formation.**

SDSS reveals record optical Einstein ring

Astronomers have found the largest optical Einstein ring known. Dubbed the Cosmic Horseshoe, the ring provides a unique laboratory for studying what the universe was like at one-fifth its present age. A team led by Vasily Belokurov at the University of Cambridge in England made the discovery.

An Einstein ring is a kind of cosmic mirage. Gravity from a foreground galaxy distorts light from a background galaxy into an arc. If the alignment between the background galaxy and the foreground "lensing" galaxy is precise enough, the distant galaxy's light becomes warped into a complete ring.

Astronomers used spectra from the Sloan Digital Sky Survey to select imaging targets for the Hubble Space Telescope's Advanced Camera for Surveys. The search netted eight optical rings.

Belokurov and his colleagues searched the SDSS catalog for multiple blue, faint companions around Luminous Red Galaxies (LRGs). Out came the Cosmic Horseshoe.

The ring measures 10.2" across and encloses some 6 trillion suns. It has an arc of 300-plus degrees.

A paper on the Cosmic Horseshoe will be submitted to *The Astrophysical Journal.* — **FRANCIS REDDY**

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TITANIC CLASH. Two massive, young, luminous stars lie in the binary system LH54–425. The "hot zone," where the stars' stellar winds collide, emits copious X rays and far-ultraviolet energy.

Titanic stars clash

Astronomers have spied a rare type of double star system in the Large Magellanic Cloud. The system, LH54–425, comprises two massive, young, highly luminous stars orbiting each other so closely they circle a common center of mass every 54 hours.

Orbiting and ground-based observatories provided insight into the interaction of these tempestuous binary stars. Georgia State University astronomer Douglas Gies and one of his graduate students, Stephen Williams, took spectra of the stars using the 4.9-foot (1.5 meters) telescope at Cerro Tololo Inter-American Observatory in Chile. Gies and Williams determined the larger star weighs in at 67 solar-masses, whereas the smaller companion is 37 solar-masses.

George Sonneborn of NASA's Goddard Space Flight Center in Greenbelt, Maryland, presented the findings May 28 at the American Astronomical Society conference in Honolulu. Sonneborn observed LH54–425 with the Far Ultraviolet Spectroscopic Explorer (FUSE) satellite. The stellar siblings buffet each other with their exhaust-like stellar winds. As the larger star sheds 500 trillion tons of mass per second, its stellar wind partly encircles the smaller companion and emits X rays and far-ultraviolet light visible to FUSE.

Within a million years, the now-separate stars may merge into a single "super star" 80 times the Sun's mass. When that superstar collapses, a supernova explosion will signal the end of LH54–425's brilliant life. **— D. P.**

Sputnik-1 — a milestone in spaceflight

For most old-timers who tell stories of seeing Sputnik soon after the world's first artificial satellite launched into space October 4, 1957, the tale has improved with decades of retelling. Few people on Earth actually witnessed the small, shiny sphere that marked the opening shot in an international Space Race whose consequences still echo around the planet.

The satellite itself was never brighter than 4th or 5th magnitude. Some instrument-equipped observers in America's "Moonwatch" program logged sightings of Sputnik, and a few private observers with binoculars and accurate visibility predictions spotted the tiny moving dot among the stars. However, what most people, including myself, observed was Sputnik's massive carrier rocket. This boxcar-sized behemoth flashed as it tumbled end over end. During its 3-month space voyage, it got as bright as a 1st-magnitude star.

Sputnik-1 presented an entirely different visual apparition to those who witnessed it. Workers at the Baykonur launch site near the Aral Sea in central Asia watched it soar into space during its near-midnight launch. For orbital mechanical reasons that only later became "obvious," what these observers saw convinced them for several desperate minutes that the launch was failing.

During the previous months' test flights of the R-7 ("Semyorka") intercontinental ballistic missile, ground observers had seen the multi-flamed rocket soar high into the sky, then arc to the northeast as it continued to climb. The trajectory was "lofted," thrown at a high angle to peak about 620 miles (1,000 kilometers) high, halfway to its impact point.

On later flights, which worked, the engines faded with growing distance while still high in the sky, probably halfway to the zenith. But for earlier flights, seared into the fresh memories of the witnesses, the light in the sky flared and then fell back toward the horizon as the engines exploded and burned. Just as with shot-down warplanes of the still-recent "Great Patriotic War" (we call it World War II), of which most space workers were veterans, a flame falling toward the horizon was a doomed craft.

S. P. KOROLEV (RSC ENERGIA)

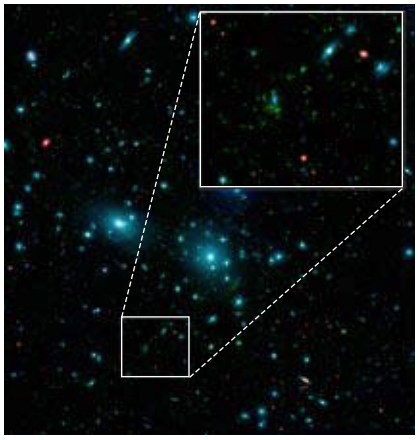
FIRST LAUNCH. Sputnik-1, the first artificial satellite, rocketed into space October 4, 1957, from the Baykonur Cosmodrome in central Asia.

As the Sputnik rocket climbed higher and higher, these observers watched, wondered, and then worried as its angular motion across the sky soon took a downward turn.

According to witnesses who later recalled the event, the handful of trajectory specialists on-site tried to console their distraught colleagues and clarify what they were actually seeing. An orbital flight was not lofted to a peak altitude, as the surface-to-surface launches had been. Instead, in order to achieve orbital velocity as efficiently as possible, it would change to a horizontal flight path as soon as it was above most of the atmosphere. With enough velocity in that lower orbit, it would successfully "fall over the receding horizon" and remain in Earth orbit.

Only rockets aimed to fall back to Earth appear to fade as they soar upward. Conversely, rockets not meant to fall back to Earth appear to head downward.

The impression that Sputnik was falling back to Earth was an illusion of perspective. Ground observers saw it moving away from them horizontally. Sputnik's dimming flame was getting lower in the observers' sky, but this was due only to the growing distance. The launch was succeeding, and did succeed. With later experience, the view that had so anguished the first satellite observers became a "normal" feature of how spaceflight should look to human eyes and brains. — **JIM OBERG**



NASA/JPL-CALTECH/GSFC/SDSS

DWARF HUNT. **Newly discovered dwarf galaxies in the Coma Berenices Cluster appear as faint green smudges in this 288-image mosaic.**

Dwarf-galaxy bonanza

The Spitzer Space Telescope reaped a bumper crop of dwarf galaxies in the Coma Berenices Cluster, reports a team led by Leigh Jenkins and Ann Hornschemeier of NASA's Goddard Space Flight Center in Greenbelt, Maryland. Containing up to several billion stars, dwarf galaxies are the most common type in the universe. In contrast, the Milky Way contains some 300 billion stars.

The team started its dwarf hunt in Coma's central region, creating a mosaic of 288 infrared images from exposures lasting 70 to 90 seconds. The mosaic covered a patch of sky about 6½ times the Full Moon's area and contained about 30,000 objects.

Visible-light observations from the 13-foot (4 meters) William Herschel Telescope in the Canary Islands established that at least 1,200 of the 30,000 objects imaged are dwarf galaxies within the Coma cluster. The scientists believe the cluster's total dwarf population could be closer to 4,000.

Jenkins and Hornschemeier presented the findings May 28 at the American Astronomical Society conference in Honolulu. Their report will appear in *The Astrophysical Journal*. — **D. P.**

Dust storm envelops Mars

Spacecraft exploring the martian surface encountered a large-scale dust storm in June, say scientists at Arizona State University (ASU) in Tempe. The scientists used the Thermal Emission Imaging System (THEMIS) aboard NASA's Mars Odyssey orbiter to monitor and map the storm's progress over the Red Planet in visible and infrared light.

Sweeping wind kicked up dust that affected the Spirit and Opportunity rovers and three orbiting spacecraft — NASA's Mars Odyssey and Mars Reconnaissance orbiters and the European Space Agency's Mars Express orbiter. Dust in the planet's atmosphere has blocked about 99 percent of sunlight reaching the martian surface. The rovers' solar panels received less sunlight, which reduced their electrical power and delayed Opportunity's foray into Victoria Crater by several days.

The storm broke out on Mars' equatorial region near Meridiani Planum during the last week of June, quickly moved into the southern highlands, and became large enough to encircle the planet in about a week. By mid-July, dust had drifted into the northern hemisphere. "We're rooting for our rovers to survive these storms, but they were never designed for conditions this intense," says Alan Stern, associate administrator of NASA's Science Mission Directorate in Washington.

A prolonged lack of sunlight could result in the rovers' electronics cooling beyond the point of recovery. — **L. L.**

BRIEFCASE

Gruber Prize

Two teams will share the 2007 Gruber Cosmology Prize. Astronomers with the High-Z Supernova Search Team and the Supernova Cosmology Project team discovered dark energy is the force causing the universe's expansion to accelerate — **L. L.**

Odd disk

Astronomers using NASA's Hubble Space Telescope and the Keck Observatory atop Mauna Kea in Hawaii found a needle-shaped debris disk around the star HD 15115. Nearby exoplanets or the star HIP 12545, located about 10 light-years away, may affect the lopsided disk's shape, causing its extremely asymmetric appearance. — **L. L.**

Moon plans

NASA has selected seven proposals to support its Lunar Advanced Science and Exploration Research (LASER) Program and the Lunar Reconnaissance Orbiter (LRO) Participating Scientist Program. The bids outline plans to develop autonomous instrument packages astronauts can deploy on the lunar surface. — **L. L.**

25 years ago in *Astronomy*

October 1982

In October 1982, *Astronomy*'s cover story asked an old question: Are we alone? "Searching for them" explored interstellar communications and theories about extraterrestrial life.

Author Jill Tarter argued life was most likely to evolve in a spiral galaxy, like our Milky Way. But, Tarter added, we may never discover other beings unless their intelligence develops the technology to communicate.

A 1,000-foot-diameter radio dish in Puerto Rico sent a coded message to globular cluster M13 in 1974. Any reply from extraterrestrials will require generations of patience — it takes 50,000 years for a radio signal to reach M13 and return to Earth. — **ERIN DOLAN**

October 1997

10 years ago in *Astronomy*

Life on Jupiter was the topic of our October 1997 feature "Diving into Europa's ocean." Planetary scientists were abuzz with the possibility that a subsurface sea on Jupiter's Earth-sized moon Europa could contain life.

The Galileo spacecraft imaged Europa's surface between 1995 and 2003 and found that it resembles a cracked ball of ice, meaning liquid water flows beneath.

En route to Pluto, the New Horizons spacecraft flew past Jupiter beginning in January 2007, conducting more than 700 observations of the planet and its surroundings. New Horizons mapped Europa's surface composition better than any previous mission. In 2016, NASA's Juno mission will further explore Europa. — **E. D.**

SUPERNOVA 20 years later

The brightest supernova since the telescope's invention taught astronomers a great deal about exploding stars — and points out a lot they still don't know. /// **BY RICHARD TALCOTT**

It's time to take a trip. Not to some far off place, mind you, but to a different time. So, dust off your time machine and set its coordinates — we're heading back to February 23, 1987.

A trip to the local library seems like the perfect cure for the Monday morning blues. You grab the latest astronomy textbook and flip open to the section that describes what happens when a massive star dies. You learn that a star born with more than about 8 solar-masses swells into a red supergiant near the end of its life. Then, once it exhausts its supply of nuclear fuel, the star's core collapses. The core then bounces outward, initiating a shock wave that blows the star apart. The details seem sketchy, but elusive subatomic particles known as neutrinos appear to play a major role.

Once the shock wave reaches the stellar surface, the star starts to brighten rapidly. Over the course of a week or so, this apparent "new star" — a supernova — reaches maximum brilliance, when it can shine as bright as the rest of its host galaxy's stars combined. Meanwhile, the compressed core becomes either a neutron star or black hole. The book's description sounds plausible, but there's an event just around the corner that will force astronomers to change their views on supernovae.

Richard Talcott *is a senior editor of* Astronomy. *He first wrote about Supernova 1987A in the June 1987 issue.*

The night it all changed

The evening of February 23 began like countless others. High in the Andes Mountains of northern Chile, astronomers prepared for another night of research, performing observing programs scheduled months earlier. Little did they know there would be no more "normal" nights for a long time.

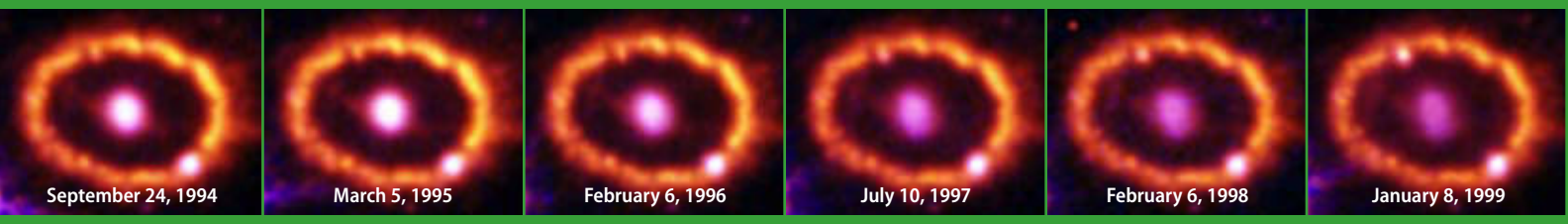
Ian Shelton and Oscar Duhalde were observing at Las Campanas Observatory. Shelton was photographing the Large Magellanic Cloud (LMC), a satellite galaxy to the Milky Way located some 160,000 light-years from Earth. Duhalde simply stepped outside his telescope dome and looked up. He and Shelton saw a bright point of light within the Cloud (Shelton saw the pinpoint on his photographic plate). A little later that night, New Zealand amateur astronomer Albert Jones sighted the same object.

The bright light turned out to be 1987's first observed supernova, earning it the moniker 1987A. But Supernova 1987A earned an even more important accolade: It was the brightest supernova in nearly 400 years — since the invention of the telescope. This exploding star promised to give astronomers a keen look into how stars die.

1987A

THE FIRST NAKED-EYE SUPERNOVA (center right) in nearly 400 years lit up the Large Magellanic Cloud in February 1987. The massive star-forming region known as the Tarantula Nebula (NGC 2070) lies to the explosion's upper left. EUROPEAN SOUTHERN OBSERVATORY

Supernova 1987A through the years



THE INNER RING of Supernova 1987A comes alive with hot spots during this 12-year period. The hot spots light up as the supernova's shock wave

Supernova 1987A's proximity to Earth told only part of the story. The blast's location in the LMC held an advantage over a Milky Way supernova. In our galaxy, where we expect an average of two supernovae per century (and we're at 403 years and counting since the last recorded one), interstellar dust obscures many supernovae. And even today, measuring the distance to a Milky Way supernova would be difficult. An LMC supernova lies close enough for astronomers to get a good look, little intervening dust gets in the way, and the distance is known accurately.

Blues for a red supergiant

It didn't take long for Supernova 1987A both to confirm and confound astronomers' expectations. The exploded star rose to magnitude 4.3 within a few days — and then held firm. Astronomers thought the supernova would peak around 1st magnitude, yet here it was, stuck some 10 times fainter than that.

After reaching this plateau, 1987A began to brighten again. On May 20, it crested at magnitude 2.9 — an easy naked-eye object, to be sure, but still well below expectations.

What was going on? Supernova 1987A's location near the huge star-forming region known as the Tarantula Nebula was a big benefit: Plenty of people had photographed this area before. Once the supernova's position was pinned down, a look at older photos revealed the loaded gun — a hot blue supergiant cataloged as Sanduleak –69°202. The cool red supergiant everyone expected was nowhere to be found.

Sanduleak –69°202 began life with about 20 times the Sun's mass. Except for this excess weight, however, it evolved much as other stars do. It spent the bulk of its life on the so-called main sequence, fusing hydrogen into helium in its core. The fusion rate dwarfed the Sun's, however — while our star will take approximately 10 billion years to exhaust its hydrogen fuel, Sanduleak –69°202 burned through its supply in several million years.

When Sanduleak –69°202's core ran out of hydrogen, the central pressure dropped. The weight of the overlying layers then compressed the interior. This raised the internal pressure and temperature until the helium ash started to undergo fusion. This process — creating heavier elements and then using them as fuel for further nuclear reactions — continued as first carbon, then neon, oxygen, and silicon formed.

At each stage of this stellar alchemy, the core temperature rose and the reaction rates spiked. It took hundreds of thousands of years to convert helium into carbon. The core silicon burned completely to iron in a few days. Throughout this process, the ongoing reactions dumped ever-increasing amounts of energy into the star's outer layers, which expanded and cooled.

> THE CORE COLLAPSED in less than a second at one-quarter light-speed.

Once the star evolved off the main sequence, it became a blue supergiant. The question for theorists: Did it remain a blue supergiant throughout its post-main-sequence years; or, did it further evolve into a red supergiant, then backtrack to become a blue supergiant before its demise? Astronomers still don't know the answer. Their best ideas weren't developed until years later, after observations of what the explosion left behind.

Collapse and rebound

In the final days of Sanduleak –69°202, iron built up in its core. Unfortunately for the star, iron is nature's most stable element. Even as the core's temperature shot past a billion degrees, nuclear reactions couldn't supply any energy. Gravity was in control.

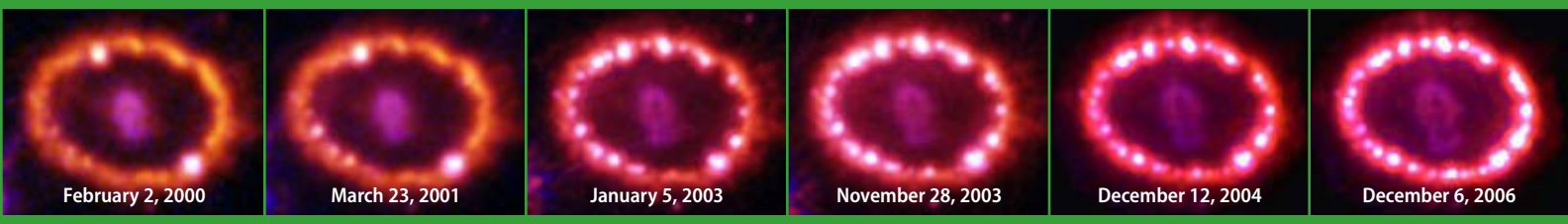
The pressure supplied by electrons, squeezed together as close as possible, could no longer support the growing weight of iron ash being dumped on the core by silicon fusion. The core collapsed in less than a second at a velocity reaching one-quarter the speed of light. Electrons were forced into iron nuclei, combining with protons to create neutrons and releasing a flood of neutrinos in the process.

Once the collapsing core's density surpassed that of an atomic nucleus, the material stiffened abruptly because the neutrons couldn't be squeezed any further. The collapse stopped and the core rebounded, generating a shock wave that marked the birth of Supernova 1987A.

Because neutrinos interact with matter so rarely, they escaped the collapsing core almost immediately. They flew through the star and into space as close to light-speed as you can imagine. Some 160,000 years later — at 2:36 A.M. EST (7h36m Universal Time) February 23, 1987 — roughly a thousand trillion trillion of these neutrinos ripped through Earth. About two dozen of them were stopped dead in their tracks by neutrino detectors located in Ohio, Japan, and the Soviet Union.

The captured neutrinos stand as the greatest triumph of astronomers' theories about how stars blow up. The elusive particles proved Sanduleak –69°202's core collapsed and that the core temperature reached tens of billions of degrees. The total energy released by the neutrinos also matched theory; they carried away 100 times more energy than did all the light and 100 times more energy than the Sun will generate in its lifetime.

The shock wave tore through Sanduleak –69°202 at a more modest pace than the neutrinos. Still, it took only about 2 hours for the shock to complete its destructive

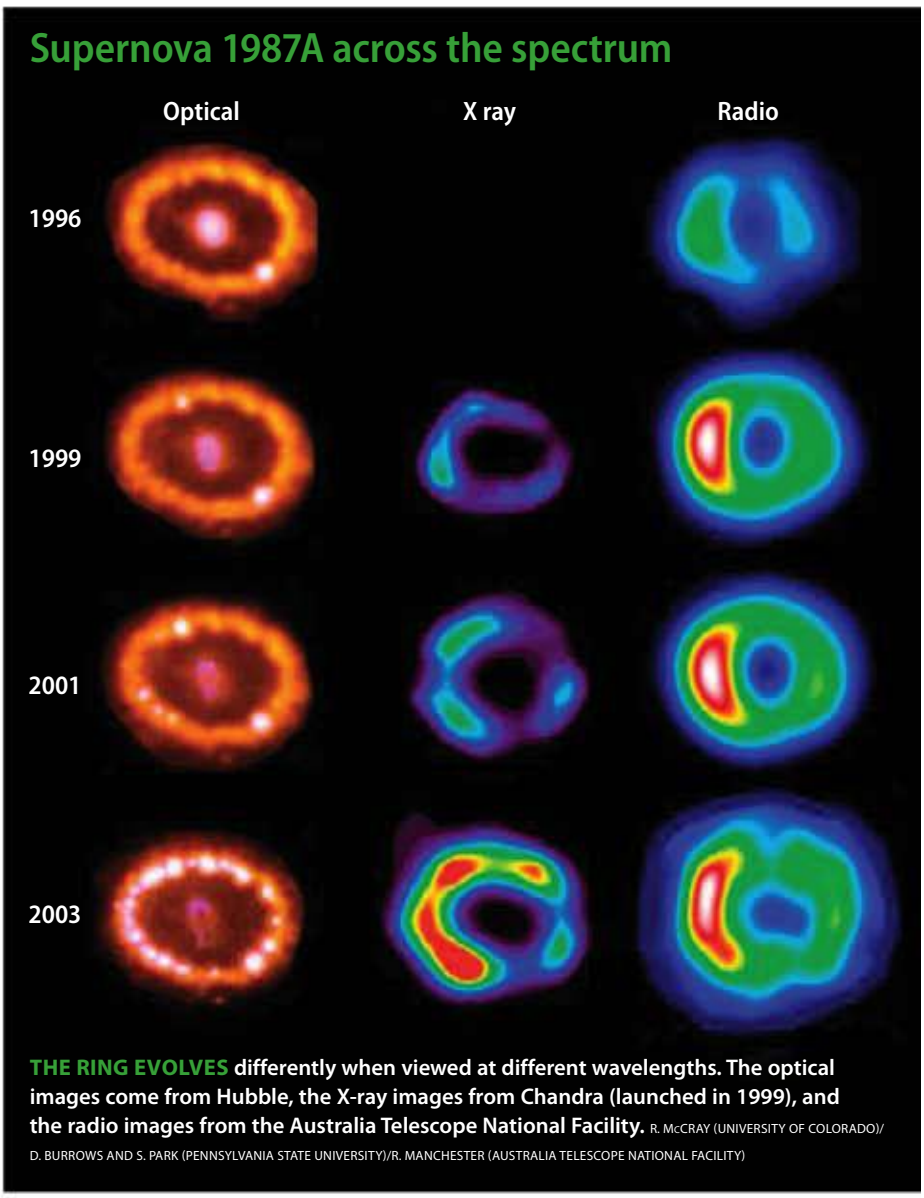


excites the ring's gases. Meanwhile, the expanding debris at the ring's center gradually grows fainter. NASA/ESA/P. CHALLIS AND R. KIRSHNER (CfA)

path through the blue supergiant and reach the surface. The star had a radius of roughly 15 million miles (25 million kilometers), some 35 times that of the Sun.

A blue supergiant packs its bulk a lot more tightly than a bloated red supergiant does. Take Orion's ruddy jewel, Betelgeuse, the brightest red supergiant in Earth's sky. It packs a mass similar to what Sanduleak –69°202 held into a volume approximately 50,000 times larger.

That difference accounts for the odd brightness profile Supernova 1987A displayed during its first few months. It failed to achieve the peak luminosity of a typical core-collapse supernova because tearing apart a smaller, denser star consumes more of the explosion's energy.



THE RING EVOLVES differently when viewed at different wavelengths. The optical images come from Hubble, the X-ray images from Chandra (launched in 1999), and the radio images from the Australia Telescope National Facility. R. McCRAY (UNIVERSITY OF COLORADO)/ D. BURROWS AND S. PARK (PENNSYLVANIA STATE UNIVERSITY)/R. MANCHESTER (AUSTRALIA TELESCOPE NATIONAL FACILITY)

The higher density also explains 1987A's unexpectedly slow rise to maximum brightness. Nuclear reactions initiated when the shock wave violently heated the blue supergiant's oxygen layer created 0.08 solar-mass of radioactive nickel. This nickel decayed to cobalt and then to iron, releasing heat in the process. As the dense outer layers of the expanding debris thinned out, they grew more transparent. The underlying material heated by radioactive decay then came into view, and the supernova brightened.

Where we stand now

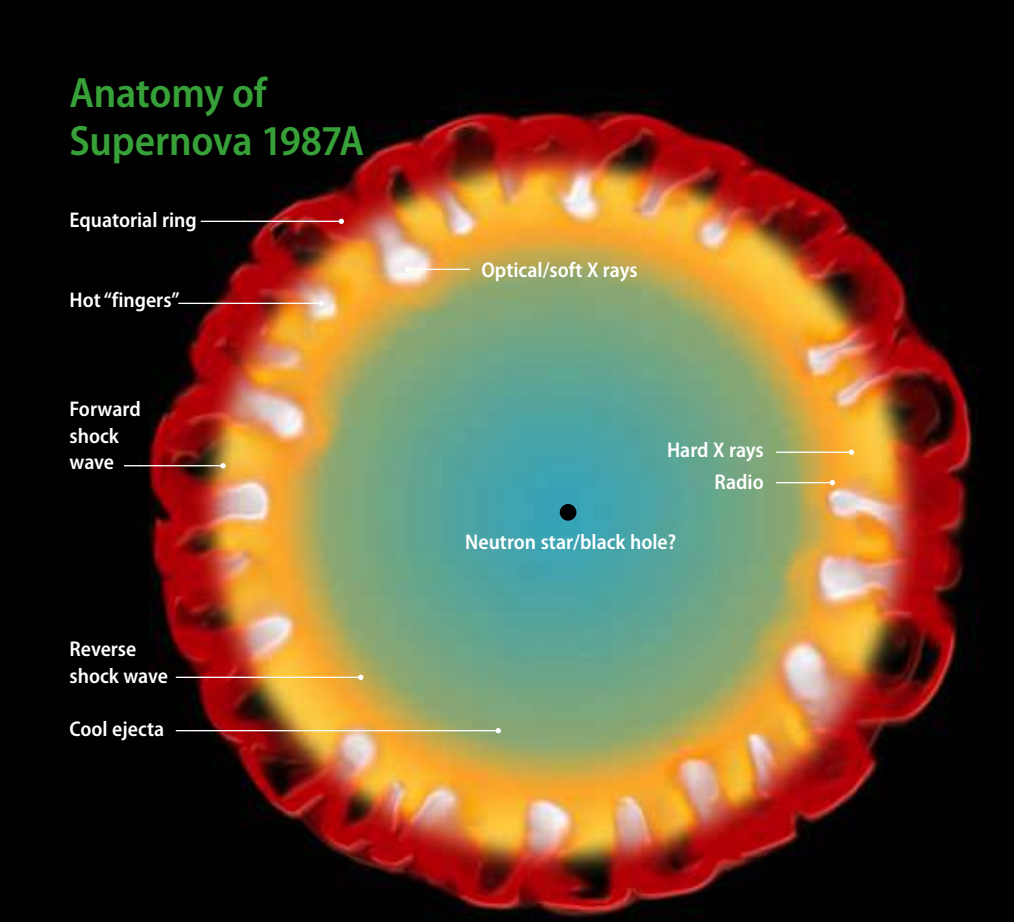
While Supernova 1987A illuminated many of the mysteries surrounding this type of stellar explosion, theorists still don't have them figured out. The most vexing question: How, exactly, does a star blow up?

The neutrinos from 1987A proved the progenitor star's core collapsed, and the supernova itself verifies a shock wave destroyed the star. But no one has established how a shock wave, formed as the inner core rebounds, fights its way through the still-collapsing outer core. Computer models show the nascent shock stalls.

In 1987, most astronomers assumed neutrinos revitalized the stalled shock. Sure, neutrinos hardly ever interact with matter. But a collapsing star's neutrinos carry away more energy than a whole galaxy generates, and the material rushing in has a density approaching that of an atomic nucleus (more than a trillion times lead's density). Astronomers figured the neutrinos somehow heated the material behind the shock enough to reenergize the explosion.

The trouble is, even the best computer models today can't get neutrinos to do the job. This doesn't mean neutrinos aren't up to the task. Astronomers who develop computer models need to perform full simulations in three dimensions — and the state of the art is just reaching that level.

With neutrinos in the fight of their lives to remain key players in destroying stars,



THE SUPERNOVA'S CURRENT STATE results largely from the explosion's shock wave interacting with a ring of gas ejected before the progenitor star went "boom." The explosion's ejecta has yet to reach this ring. NASA/CXC/M. WEISS

astronomers are seeking alternative energy sources. Sound waves could be the solution.

Computer simulations by University of Arizona physicist Adam Burrows show turbulence surrounding a star's collapsed core sets it oscillating. The acoustic waves generated then spread out into the still-collapsing envelope. Although neutrinos carry away the vast bulk of a supernova's energy, the stalled shock absorbs little of their energy. On the other hand, matter soaks up almost all of the acoustic energy.

The sound waves push aside infalling gas, clearing a path that may allow neutrinos to reinvigorate the stalled shock. This seems to work — at least in the computer.

A third way to get the energy needed is through magnetohydrodynamics — converting the star's rotational energy into magnetic energy. Computer simulations show magnetic energy can drive a stellar explosion if the star's iron core rotates once every 2 seconds or so. Such a rate would lead to the remnant neutron star spinning every 10 milliseconds — a rate not yet found in nature but not beyond theoretical limits. All magnetohydrodynamic explosions occur asymmetrically, with the shape ultimately determined by the magnetic field's structure.

Sanduleak –69°202's final years

Supernova 1987A's unexpected progenitor star presented another challenge to astronomers trying to read nature's book on star death. Clues to a solution started appearing within months of the explosion.

Astronomers noticed something odd when the supernova's spectrum showed strong lines of nitrogen and other heavy elements. Nothing unusual about that — massive stars create these elements out of lighter ones, and the explosions return them to the interstellar medium. In Supernova 1987A's case, however, spectra showed the nitrogen-rich gas moving far too slowly to be explosion debris. Instead, the material must have dated from well before the blast.

Pictures taken in 1990 by the European Southern Observatory's New Technology Telescope showed a gaseous ring encircling the supernova's location. Subsequent Hubble Space Telescope images revealed a bright equatorial ring and two fainter rings considerably farther away. Finally, theorists had something to work with.

The first hypothesis imagined Sanduleak –69°202 living as a red supergiant for several hundred thousand years. It then evolved into a blue supergiant for its final few tens of thousands of years.

A red supergiant has a powerful stellar wind, which carries away several solar-masses of gas from the surface at a few thousand miles per hour. But a blue supergiant's wind blows 100 to 1,000 times faster. Once it kicks in, it piles up material from the red-supergiant phase like a snowplow clearing a street after a blizzard.

In Sanduleak –69°202's case, the stellar winds created a gas ring currently some 1.3 light-years in diameter. The explosion lit up this equatorial ring, which imparted its signature in early supernova spectra. The supernova's shock wave is now hitting the ring, causing it to glow brighter. In this scenario, the two outer rings formed during an earlier episode of mass-loss.

This single-star model makes sense, but some astronomers don't buy it. Philipp Podsiadlowski of Oxford University champions the idea that Sanduleak –69°202 started out as a binary star instead. In this picture, the progenitor star was a red supergiant until it merged with a companion some 10,000 years before the explosion.

In such a merger, which approximately 10 percent of all massive stars experience, the companion transforms the red supergiant to a blue supergiant. The merger also dredges up helium from the star's interior, which could explain the high abundance of this element seen in early spectra of 1987A. And in a final twist, models suggest a merger naturally creates a triple-ring nebula like that seen around Supernova 1987A.

A few astronomers even propose Sanduleak –69°202 never was a red supergiant. Nathan Smith of the University of California, Berkeley, thinks the star might have been a Luminous Blue Variable (LBV), a class of unstable blue supergiants characterized by irregular and occasionally violent outbursts that can eject several solar-masses of material. LBVs in our galaxy often show the kind of nebulosity seen around Supernova 1987A.

Smith thinks LBVs can explode directly. He suggests Eta Carinae, the most spectacular LBV in our galaxy, could explode at any time (see "The supernova next door," June 2007). Smith believes the structure

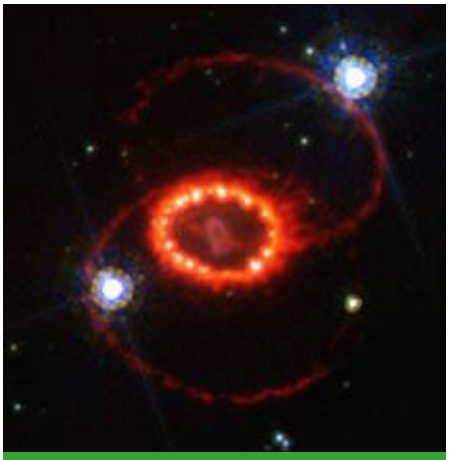
seen around Supernova 1987A is better explained by Sanduleak –69°202 having been an LBV than by having experienced an earlier red-supergiant phase.

Where the action is

For astronomers observing Supernova 1987A in 2007, the equatorial ring gets most of the attention. From 3 months to 10 years after the explosion, the budding supernova remnant dimmed steadily. That began to change around 1997, when the supernova's expanding shock wave hit the ring's inner wall. As the shock rams into denser material, the gas heats up and starts to glow. The interaction produces radiation at wavelengths from low-energy radio waves all the way through the optical spectrum to high-energy X rays.

The ring's structure didn't turn out like astronomers expected, either. Instead of brightening uniformly, the ring began shining brightly in a single hot spot. As time went on, other spots turned on. Now, in 2007, more than two dozen hot spots adorn the ring like pearls on a necklace.

The spots are fingers of hot gas attached to the ring's inner wall that point back toward the explosion. They apparently formed when the shock wave smashed into the ring, giving birth to a second shock wave (a "reverse shock") that moves inward. The hot spots likely turned on at different times because the initial shock wave either started out asymmetric or moved faster in some directions than others.



A THREE-RING CIRCUS surrounds Supernova 1987A. The rings may be remnants from winds during the progenitor star's later years, from the merger of a companion star, or from mass-loss when it was a Luminous Blue Variable. NASA/STScI/CfA/P. CHALLIS

THREE RINGS now glow around Supernova 1987A, while wispy tendrils of gas in the Large Magellanic Cloud surround the explosion site. Expect more fireworks in the coming decades as supernova debris crashes into the rings. NASA/ESA/THE HUBBLE HERITAGE TEAM (AURA/STScI)

Currently, astronomers are observing four separate regions of optical emission: the supernova ejecta itself, racing outward at nearly 1,900 miles per second (3,000 km/s); the equatorial ring, barely moving at 6 miles per second (10 km/s); the shocked ring material, or hot spots, with velocities from about 200 to 300 miles per second (300 to 500 km/s); and the reverse shock, heading back into the ejecta at nearly 9,000 miles per second (15,000 km/s). Astronomers also target the explosion's remains with radio, infrared, and X-ray telescopes.

Back to the time machine

What does the future hold for Supernova 1987A? Let's get back in our time machine and head to the future. No need to read books this time around — the future is written in the stars.

The first act of our story will play out over the next several years. The explosion's debris continues apace and will soon run into the equatorial ring, setting off fireworks bound to capture the attention of every astronomer.

As the expanding debris slowly destroys the ring, the supernova will brighten further. Scientists expect 1987A to be roughly 10 times brighter in 2017 than it is today, and maybe 100 times brighter than now by 2027. Once the ring's gone, the debris will resemble a typical young supernova remnant. And, perhaps, the material will thin enough to reveal the neutron star presumably left at the center.

One day in the distant future, the expanding shock wave may trigger another cloud of interstellar gas and dust to start contracting. The cloud — enriched with heavy elements from earlier supernovae — should produce at least a few stars heavier than 8 solar-masses. Millions of years from now, stellar evolution will bring an end to one of those massive stars. If our ancestors are around to see it, they'll likely know exactly what caused the star to explode. And they can look back to 1987 as a watershed leading to their understanding.

ONLINE EXTRA Why haven't we seen the neutron star 1987A left behind? The answer awaits at www.astronomy.com/toc.

How the Big Bang forged the

Nuclear reactions in the universe's first minutes made the lightest elements. This find changed scientists' minds about cosmic origins.

/// BY ADAM FRANK

The birth of deuterium

THE MOST FRAGILE of the light elements, deuterium (H^2), formed in the universe's first minutes when protons and neutrons stuck together. All astrophysical processes destroy this nucleus, so its abundance has been declining since the Big Bang. Deuterium's absorption feature in the spectra of quasars helps astronomers pin down its original abundance. The fusion reactions illustrated here involve photon emission; other, faster reactions also were present.

ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

first elements

Moments after the Big Bang, as the universe quickly expanded from an unimaginably dense, impossibly hot state, something wonderful happened. Over the course of the first 3 minutes, the first elements were born.

Every instant of every day, evidence that the universe began in a cosmic fireball stares us in the face. Proof that the universe was once hot and dense resides in the very atoms from which the stars, planets, and we ourselves are built.

Big Bang nucleosynthesis — BBN, for short — is the field of astrophysics linking the observed abundances of the chemical elements to theoretical predictions based on the Big Bang. Along with the universal redshift of galaxies and the cosmic microwave background, BBN is one of the great pillars on which modern cosmology stands.

BBN is a remarkable mix of precise astronomical observation and exacting physical theory. Using only the abundances of the lightest elements, hydrogen and helium, BBN spins out a detailed picture of our cosmic beginnings. It is a remarkable tale, and a grand triumph of science's power and precision. Most amazing of all, the events that drive this story, with consequences stretching across space and time, unfolded in little more than the span of a typical TV commercial break.

Elemental origins

We recognize more than 116 distinct chemical elements today. Each element appears different to us — copper is metallic and shiny, while sulfur is yellow and powdery — because the atoms making each element differ. It's hard to believe scientists were still vigorously debating the reality of atoms even 100 years ago. But once scientists confirmed the reality of the atom in the early decades of the previous century, they began probing its internal structure.

Every atom, they found, contains a central nucleus composed of one or more protons, which carry a positive electric charge. Hydrogen, the simplest and most abundant element, has a single proton in its nucleus. It's the number of protons in a nucleus that distinguishes one element from another.

The nucleus also may contain another particle, called a neutron. It's slightly heavier than the proton and lacks an electrical charge. The number of neutrons in a nucleus is what distinguishes one variation of a single element — called an isotope — from another.

A third kind of particle, the negatively charged electron, orbits each nucleus at great distance. Compared to protons and neutrons, electrons weigh next to nothing. The discovery of atomic, and then nuclear, structure answered questions about the nature of matter that had haunted philosophers and scientists for 2,000 years.

Until the 1930s, physicists could not explain elemental abundances. Why is it so much easier to find hydrogen atoms than, say, iron atoms? And good luck finding a lutetium atom. Hydrogen is vastly more abundant than iron, which itself is vastly more abundant than lutetium. Why?

In 1937, German-American physicist Hans Bethe (1906–2005) was returning by train to his Ithaca, New York, home following a nuclear physics conference in Washington. It just

Adam Frank *is an astrophysicist at the University of Rochester in New York. His previous* Astronomy *article was March 2007's "The Livio Code."*

might have been the most productive train ride in history: By using the time to explore equations for the newly developing science of nuclear physics, Bethe discovered the secrets of stellar fusion. Using the high temperatures and densities inferred by astronomers to exist at the centers of stars, Bethe showed how simple elements can be squeezed together to form more complex ones, a process that releases energy.

In a single stroke, Bethe showed how the fusion of elements fuels the stars, that stellar cores are alchemical furnaces transmuting one kind of matter into another. Bethe's success convinced physicists and astronomers that the handiwork of stars could explain all the elements and their abundances.

They were both right and wrong.

In 1957, British astronomers Geoffrey and Margaret Burbidge, American astronomer Willy Fowler, and British astrophysicist Fred Hoyle published a monumental work that put the theory of stellar nucleosynthesis on firm ground. Often known as B^2FH, the paper refined earlier studies into a single coherent picture that accounted for the observed abundances of elements — almost.

HIDING IN astronomers' journals was a paper that could solve the puzzle, but its solution meant opening a door to the dawn of time.

While the astronomers could nail down elements like carbon, oxygen, and iron, their model couldn't get the simplest elements right. The theory predicted hydrogen and helium proportions that were completely different from what astronomers observe.

Stellar nucleosynthesis predicted a cosmos with too little helium. Observations show that helium makes up about 24 percent of the universe. Everything heavier accounts for less than 2 percent of the total, and all the rest is hydrogen. For years, astronomers were left scratching their heads at this glaring failure in the midst of a spectacular success.

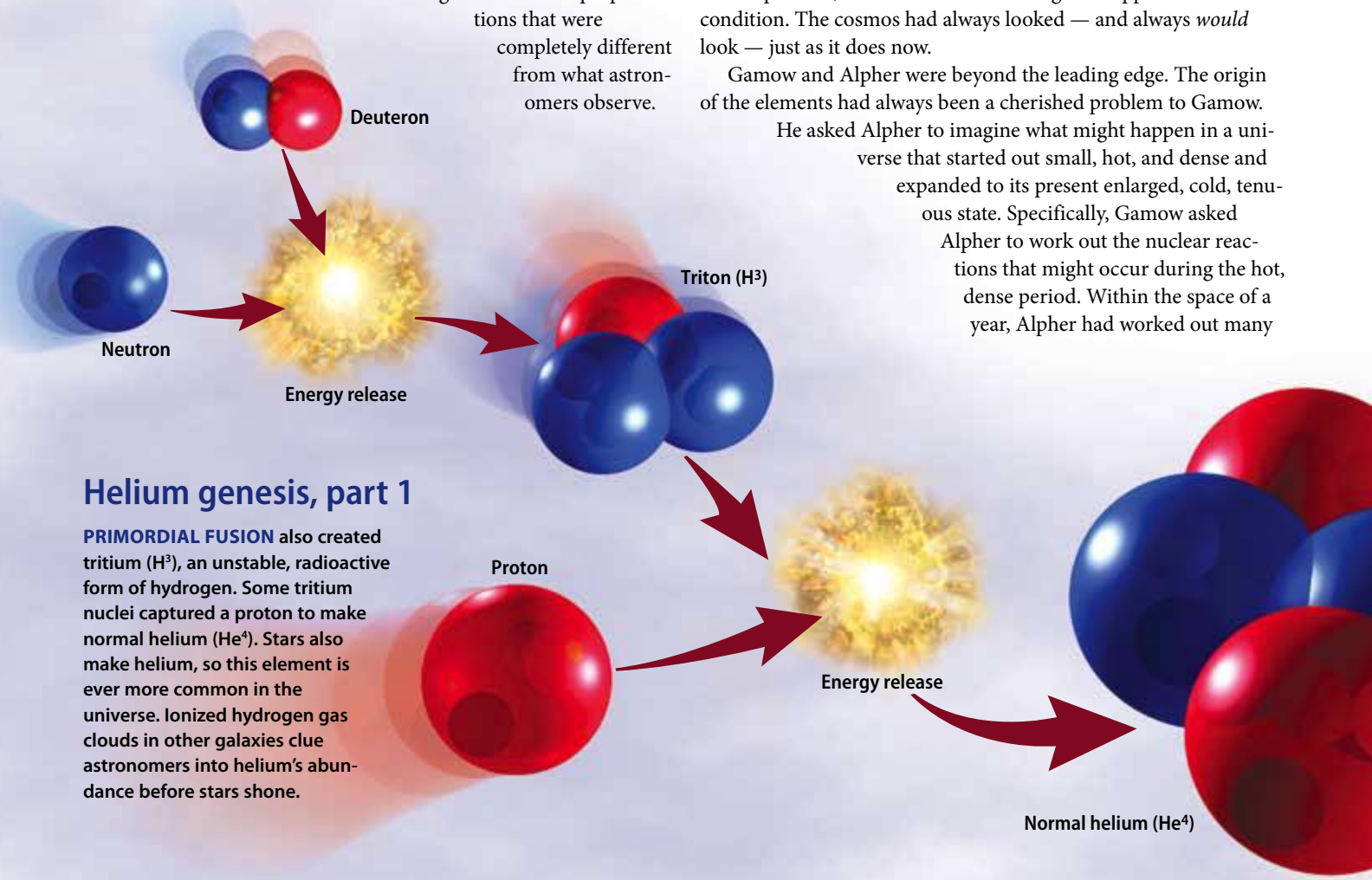
In fact, the answer had already been found and forgotten. Hiding in their journals was a paper that could solve the light-element puzzle. But accepting the solution it offered meant opening a door to the dawn of time.

Beyond steady state

In 1948, Ralph Alpher (1921–), a wiry, young graduate from George Washington University, wrote a doctoral thesis that began, for the first time, at the beginning. Under the tutelage of George Gamow (1904–1968), a Russian-refugee physicist known as much for his heavy drinking as for his genius, Alpher set out to describe nuclear physics in the realm of an infant expanding universe.

It's difficult to imagine now how bold, how radical this endeavor was. In 1948, few scientists were thinking about cosmology, and those who were had locked themselves into the so-called steady-state model. Steady-state cosmology held that, even with expansion, the universe never changed its appearance or its condition. The cosmos had always looked — and always *would* look — just as it does now.

Gamow and Alpher were beyond the leading edge. The origin of the elements had always been a cherished problem to Gamow. He asked Alpher to imagine what might happen in a universe that started out small, hot, and dense and expanded to its present enlarged, cold, tenuous state. Specifically, Gamow asked Alpher to work out the nuclear reactions that might occur during the hot, dense period. Within the space of a year, Alpher had worked out many



Helium genesis, part 1

PRIMORDIAL FUSION also created tritium (H^3), an unstable, radioactive form of hydrogen. Some tritium nuclei captured a proton to make normal helium (He^4). Stars also make helium, so this element is ever more common in the universe. Ionized hydrogen gas clouds in other galaxies clue astronomers into helium's abundance before stars shone.

AIP EMILIO SEGRÈ VISUAL ARCHIVES

GEORGE GAMOW, a Russian-American scientist and a pioneer in nuclear physics, suggested the universe originated from a hot sea of radiation and particles.

AIP EMILIO SEGRÈ VISUAL ARCHIVES

RALPH ALPHER and Gamow found that observed abundances of light elements, like hydrogen and helium, are a consequence of a hot, expanding early universe.

NUCLEAR SPEAK

BIG BANG
The event that spawned space, time, and the expanding universe.

DEUTERON
A hydrogen nucleus (proton) bound to a neutron; a nucleus of deuterium.

FUSION
The merger of protons and neutrons to form atomic nuclei, accompanied by a characteristic energy release. The fusion of hydrogen into helium powers the Sun.

NUCLEON
A proton or neutron.

NUCLEOSYNTHESIS
Processes in stars and the early universe that create new atomic nuclei from existing protons and neutrons.

TRITON
A hydrogen nucleus (proton) bound to two neutrons; a nucleus of tritium.

of the crucial aspects with meticulous attention to mathematical detail. It was a triumphant physics *tour de force* — but one the scientific establishment promptly forgot. While Alpher's first calculations contained some missteps, they got the fundamentals of Big Bang nucleosynthesis correct.

Alpher, along with collaborator Robert Herman, spent the next few years refining his models and examining the implications of a cooling and expanding universe. The team even predicted the presence and temperature of a cosmic microwave background from the redshifted light released when the universe had cooled enough that electrons could combine with nuclei to form atoms.

Alpher said he and Herman expended "a hell of a lot of energy" giving talks to convince astronomers the results deserved a serious look. But their work received little attention, and, in a tragedy of cosmic proportions, the two physicists ultimately gave up in frustration. Alpher left academia to work for General Electric, while Herman moved on to General Motors Research Laboratories.

In the mid-1960s, the weight of new data finally forced the acceptance of Big Bang cosmology. But, even then, Alpher's immense contribution was largely ignored, with credit given almost solely to Gamow.

In the years since, others have refined the picture Alpher and Gamow first glimpsed. Its predictions of simple-element abundances prove that we understand something about cosmic origins. The secret of BBN, the secret Alpher, Gamow, and Herman knew first, occurs just after the cosmos began.

Fusion and the Big Bang

Astronomers see galaxies rushing away from one another in today's expanding universe. But if we could run cosmic evolution backward, everything would draw together. The cosmos would become denser and hotter. As the clock runs backward toward the Big Bang, structures like galaxies melt into a thickening soup of primordial gas. Run the clock back further, and the gas also breaks down into a smooth, ultrahot sea of protons, neutrons, and other subatomic particles. At this point, the universe has a temperature of about 100 billion K. A teaspoon of cosmic matter weighs more than 100,000 tons.

This is where BBN begins. By going back only to about 0.01 second after the beginning, physicists limit themselves to a temperature and density domain they can work with comfortably. More than 60 years of particle accelerator experiments validate their understanding. Running the clock forward from 0.01 second, BBN describes the universe's next 3 minutes in astonishing detail.

From the chaos of those first moments, fusion physics leaves an unalterable imprint on the universe. To choreograph this dance, BBN requires two critical components — an understanding of fusion processes and the physical conditions in the young cosmos.

A hydrogen nucleus (denoted H) is a single proton. Helium nuclei (denoted He^4) have two protons and two neutrons. Fusing hydrogen into helium is a battle between electromagnetism and the strong nuclear force, two of the four forces that govern the cosmos.

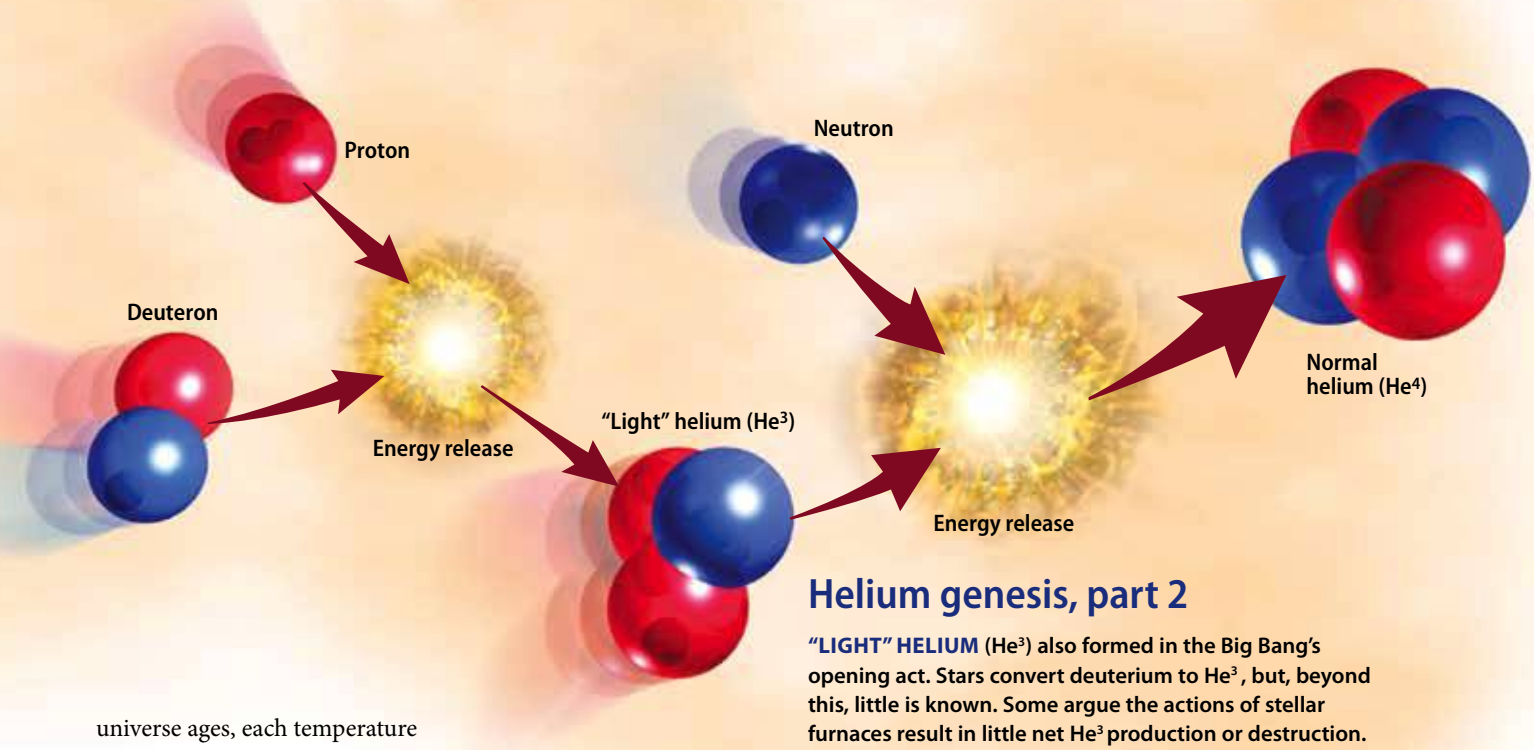
While it's easy to push neutral neutrons together, every proton carries a positive electric charge. Like charges repel via the electromagnetic force, which gets stronger as the particles get closer. (It's like trying to force the same poles of two magnets together.) To fuse into more complex nuclei, protons must overcome this electromagnetic barrier.

The strong nuclear force is more powerful than electromagnetism. But it has the odd property of kicking in only when protons and neutrons get really close to each other.

At a high enough density and temperature, protons whiz around fast enough that some collisions have the energy to push them past the electromagnetic barrier and trigger fusion. But because the universe is expanding and cooling, Big Bang nucleosynthesis becomes a race against time.

Beat the clock

The universe's rapid expansion and cooling leaves only a brief window for nuclear fusion to occur. Einstein's theory of relativity specifies the expansion rate; nuclear physics specifies the temperature and density at each moment in cosmic history. But as the young



Helium genesis, part 2

"LIGHT" HELIUM (He³) also formed in the Big Bang's opening act. Stars convert deuterium to He³, but, beyond this, little is known. Some argue the actions of stellar furnaces result in little net He³ production or destruction. If this is true, the total amount of deuterium and He³ remains approximately constant.

universe ages, each temperature and density regime allows only certain particles to exist and certain kinds of reactions between those particles.

Fusion can't start until protons and neutrons — collectively, nucleons — form. A millionth of a second after the Big Bang, when the temperature is a mere 2 trillion K, the universe has cooled enough that quarks can coalesce into protons and neutrons.

About 1 second after the Big Bang, the ratio of neutrons to protons becomes fixed and fusion reactions can begin. But this window of opportunity lasts only 3 minutes. After this time, the cosmos will have expanded and cooled so much, it can't support fusion reactions at all.

As BBN begins, protons outnumber neutrons 7 to 1. The difference emerges because neutrons are slightly heavier than protons, and this mass difference allows a neutron to decay spontaneously into a proton, electron, and a ghostly particle called a neutrino. Left to its own devices, a lone neutron will, on average, decay into a proton and an electron in just 15 minutes.

Save the neutron

Fusion saved the neutrons. They collided with the abundant protons and fused together as a deuteron — the simplest compound nucleus. A deuteron, a nucleus of deuterium (denoted H^2), is a stable isotope of hydrogen.

Deuteron formation can't start up in earnest until about 100 seconds after the Big Bang. Once it does, it triggers a cascade of reactions that leads to nuclei with 2 protons and 2 neutrons — helium. For example, a deuteron may collide with a neutron to make tritium (H^3), which then collides with a proton to make normal helium (He^4). Or the deuteron could collide with a proton to make a nucleus of light helium (He^3), which then collides with a neutron to make He^4.

Other reactions create a small amount of lithium and beryllium. But that's as far down the periodic table as we can go before fusion grinds to a halt. More complex elements must await the first stars — several hundred million years in the future.

Scientists must follow all possible reactions, their pace, and all their products. Most importantly, physicists must perform these calculations in a cosmic background of continually changing temperature and density. It is a tremendous task. But when the smoke clears, BBN predicts exactly how much hydrogen, helium, deuterium, and other light elements exist in the cosmos.

FUSION reactions begin about 1 second after the Big Bang and last only 3 minutes.

From H to us

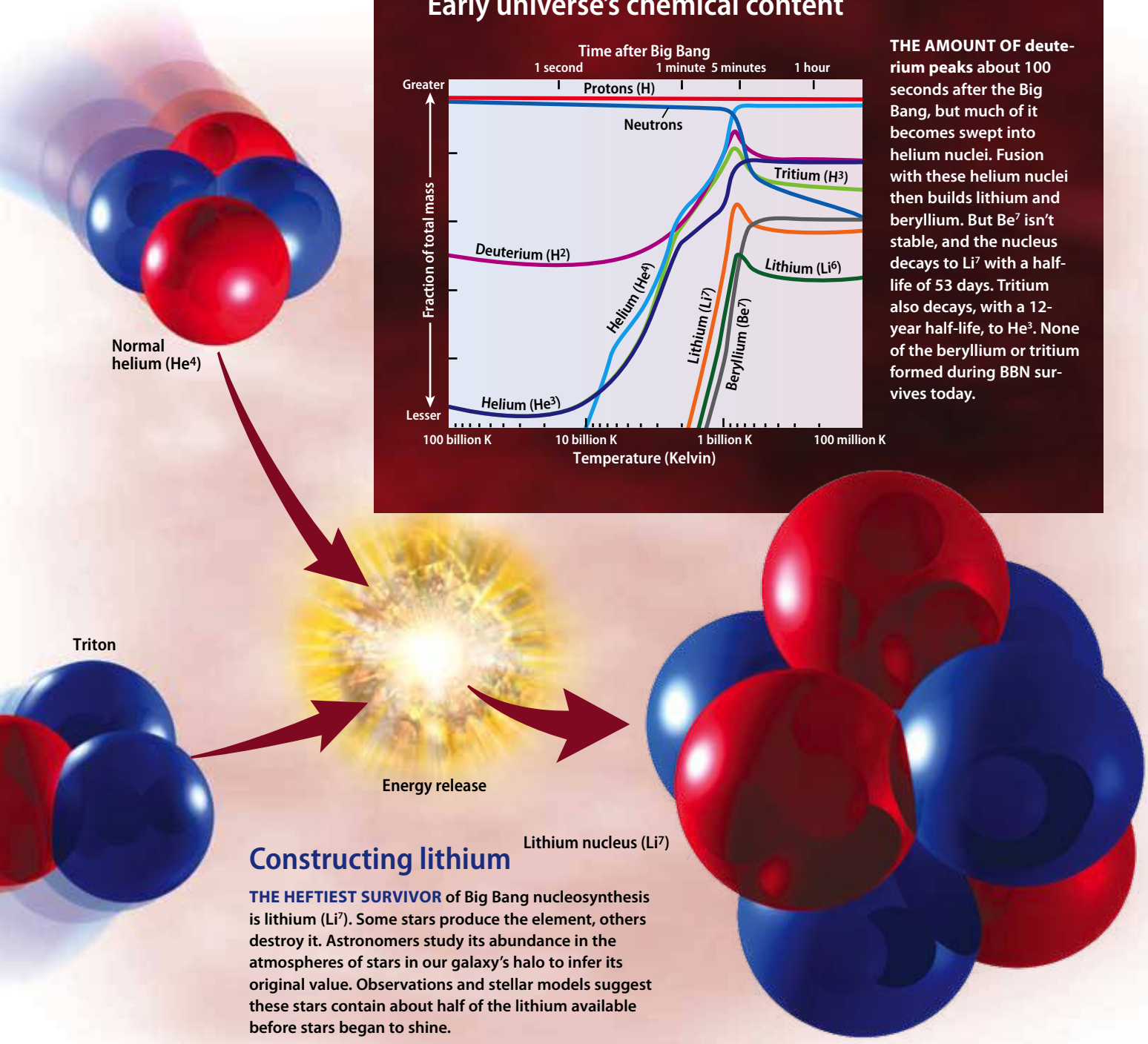
While stellar nucleosynthesis could not match the observation that helium makes up 25 percent of the cosmos' mass, Big Bang nucleosynthesis nails it right out of the gate. BBN's main prediction is the copious early production of He^4. This result ends up being remarkably insensitive to details in the calculation. Barring major changes to the basic scenario, BBN always leads to helium production close to the observed amount. Fundamentally, all that really matters is that a Big Bang occurred.

Helium abundance isn't all that sensitive to conditions in the early universe, but deuterium is another story. The denser the early universe was at the beginning of the fusion era, the more likely it is that all the deuterium would end up in helium nuclei. That some deuterium remains — even 0.01 percent relative to hydrogen — tells physicists something about the young universe.

This and other trace elements let physicists determine the universe's baryonic density — a measure of matter like protons and neutrons — with high accuracy. Using precision measurements of

Early universe's chemical content

THE AMOUNT OF deuterium peaks about 100 seconds after the Big Bang, but much of it becomes swept into helium nuclei. Fusion with these helium nuclei then builds lithium and beryllium. But Be^7 isn't stable, and the nucleus decays to Li^7 with a half-life of 53 days. Tritium also decays, with a 12-year half-life, to He^3. None of the beryllium or tritium formed during BBN survives today.



Constructing lithium

THE HEFTIEST SURVIVOR of Big Bang nucleosynthesis is lithium (Li^7). Some stars produce the element, others destroy it. Astronomers study its abundance in the atmospheres of stars in our galaxy's halo to infer its original value. Observations and stellar models suggest these stars contain about half of the lithium available before stars began to shine.

light-element abundances in regions as diverse as stars and intergalactic clouds, astrophysicists now can claim that the density of normal matter in the cosmos is only around 2 percent of the value needed to halt the universe's expansion in the future. Most astronomers believe the universe's total density (the sum of all kinds of matter and energy) exactly equals this critical density.

Because BBN predicts such a tiny fraction for stuff like us, the rest of the universe must be composed of dark matter and dark energy — "dark" in the sense that astronomers don't yet understand what they are. In this way, BBN not only has provided proof that a Big Bang must have occurred. It also gives us strong evidence that we have much to learn about our universe.

Much has changed from Alpher and Gamow's first calculations 60 years ago to the current era of precision cosmology. Now, a wealth of high-quality data lets scientists test competing cosmological models. But while astronomers have firm reasons for believing in the reality of the Big Bang, they don't need to rely on cutting-edge physics to do so. Big Bang nucleosynthesis shows us that a brief period of well-understood physics has consequences that trickle down 13.7 billion years to the universe we observe.

ONLINE EXTRA Alpher and Herman predicted the presence of a cosmic microwave background. Learn more about this facet of their work at www.astronomy.com/toc.

Family ties reveal asteroid origins

Tracing the history of space rocks uncovers a cluster with a common origin.

/// BY DANIEL D. DURDA

Created a scant 5.8 million years ago, the Karin cluster is one of the youngest known asteroid families. Scientists uncovered this fledgling family's origins while studying groups of main-belt asteroids with closely related orbits. They wondered what would happen if they traced the asteroids' orbits backward in time. When they did, they made a startling discovery — the orbits of 39 asteroid fragments converged, revealing their common origin. This asteroid group, which has since grown to 90 members, is known collectively as the Karin cluster.

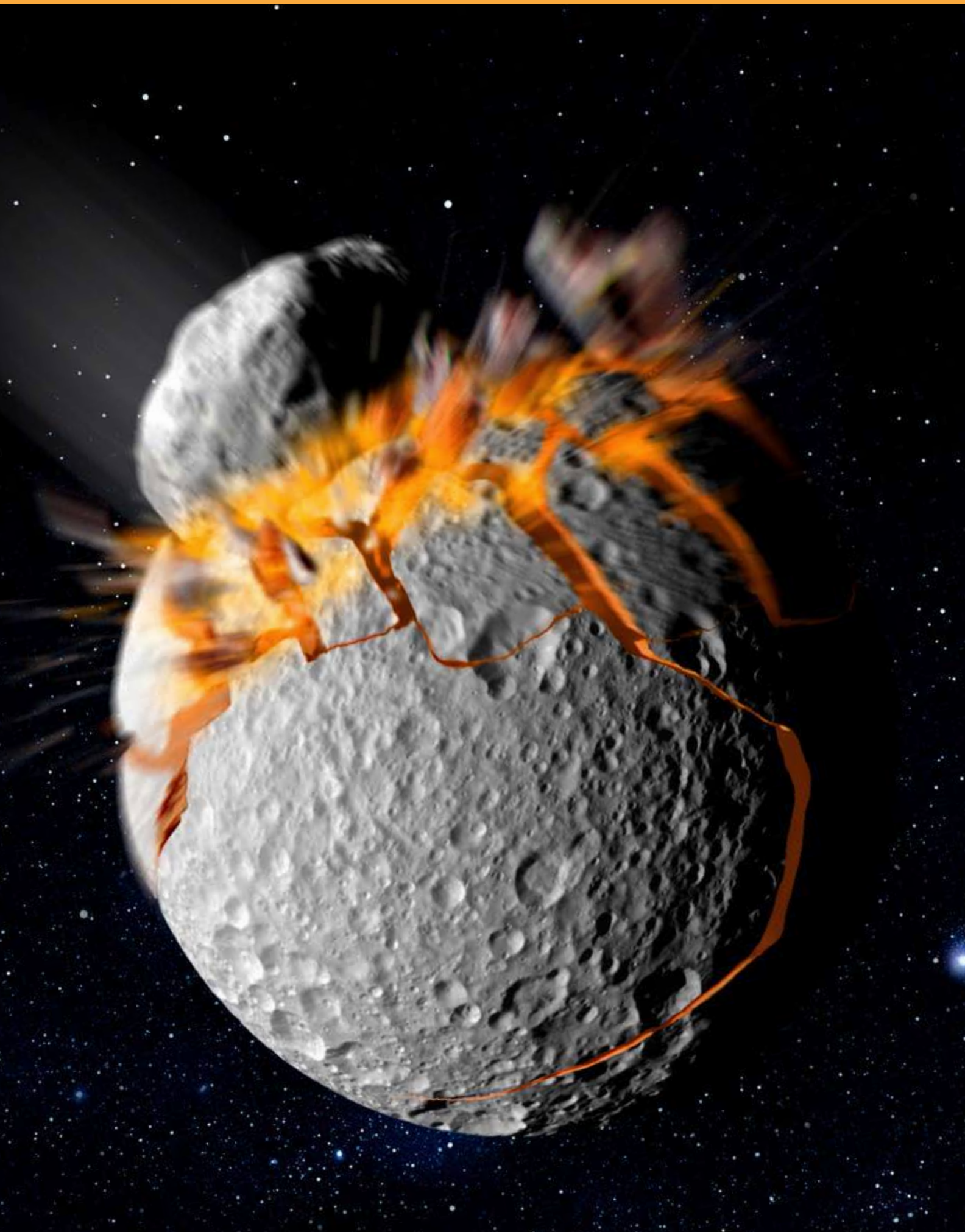
Dust to dust

Dust bands are a part of the zodiacal cloud, the complex of asteroid and comet dust in our planetary system. Revelations about these dust bands, and subsequent asteroid-classification efforts, led to the discovery of the 90-member Karin asteroid family.

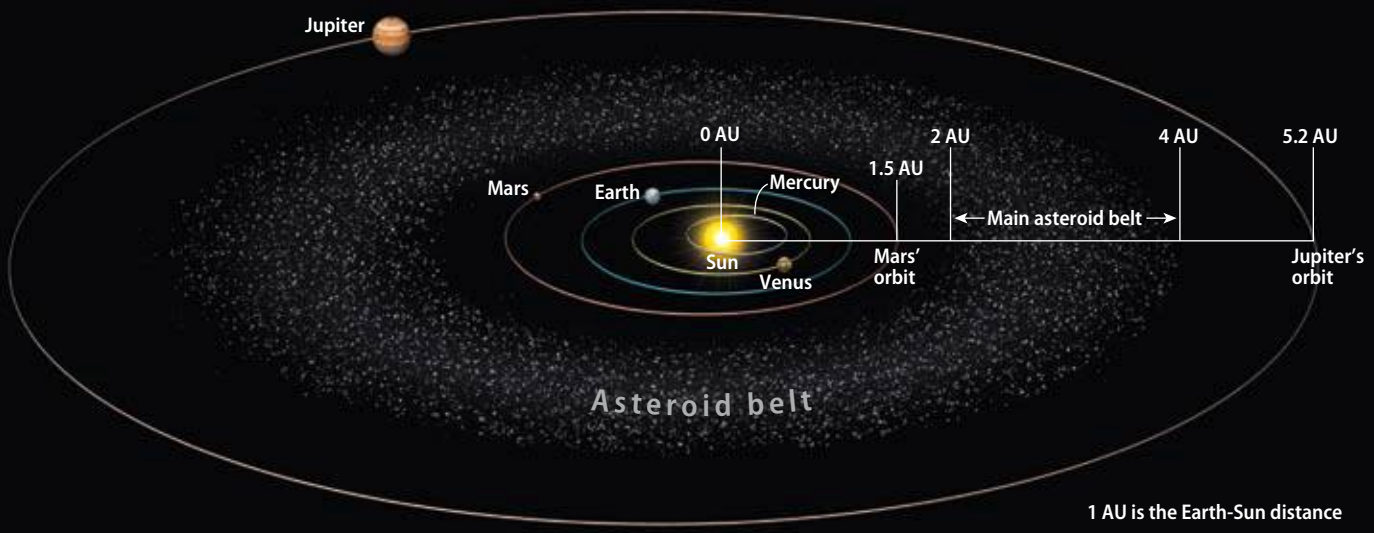
The Infrared Astronomical Satellite (IRAS) — a joint project of the United States, United Kingdom, and the Netherlands — first detected dust bands superimposed on the relatively smooth background zodiacal cloud in 1983. Following the dust bands' discovery, Stan Dermott, a professor

Daniel D. Durda, *a planetary scientist with the Southwest Research Institute in Boulder, Colorado, specializes in wandering objects such as moons and asteroids.*

THE KARIN CLUSTER formed a mere 5.8 million years ago. Computer models suggest an asteroid more than 3.5 miles wide (5.75 km) slammed into the 20-mile-wide (33 km) Karin parent body at about 14,400 mph (23,175 km/h). The fragments circle the Sun in roughly similar orbits. DANIEL D. DURDA (SWRI)



Where main-belt asteroids live



MAIN-BELT ASTEROIDS orbit the Sun between Mars and Jupiter at a distance of 2–3.3 AU. These asteroids travel about the Sun in stable, nearly circular orbits that are slightly inclined with respect to the plane of the solar system. *ASTRONOMY:* ROEN KELLY

of astronomy at the University of Florida in Gainesville, and my Ph.D. thesis advisor, noticed a connection between the apparent ecliptic latitudes of the most prominent dust bands — two pairs straddling the ecliptic at low latitudes and one pair at a higher latitude of 10° — and the orbital inclinations of major asteroid families in the main asteroid belt, which lies between Mars and Jupiter.

Asteroid families are remnants of larger parent asteroids broken apart in collisions with other asteroids millions to billions of years ago. Dermott reasoned that as member asteroids of the three largest families — Koronis, Themis, and Eos — gradually grind away due to ongoing collisions with other asteroids, the resulting dust supplies the zodiacal cloud with interplanetary dust particles having orbital elements similar to their parents'.

On Dermott's suggestion, I used the amount of dust in the infrared bands associated with the three big asteroid families to try to calibrate how much dust comes from all the other main-belt asteroid collisions. Our research group at the University of Florida modeled the collisional and orbital evolution of dust from these families and simulated the IRAS observations of the resulting modeled dust bands. Overall, the fits were pretty good, but the 10° dust bands never quite matched up with the inclination of the Eos family. This suggested we were missing a piece of the puzzle. Might some other families be contributing to the dust bands?

Do-it-yourself science

David Nesvorný, a research scientist at the Southwest Research Institute in Boulder, Colorado, and an expert in the orbital evolution of minor planets, analyzed the orbital elements of a large collection of asteroids to identify asteroid clusters with closely related orbits. When an asteroid is broken apart in a disruptive collision, its fragments are ejected into their own orbits around the Sun. These new orbits are not much different than that of the parent's.

Using 3-D visualization software he wrote, Nesvorný closely examined the recently classified asteroid families. He was especially interested in finding new, small families astronomers hadn't previously recognized because too few members were known for statistically meaningful groupings to appear. Fragments produced by smaller, and presumably more recent, collisions would have suffered fewer impacts after the parent asteroid's breakup. These smaller, younger families should preserve the effects of a disruptive impact and, therefore, provide a better natural laboratory for understanding impact physics than do the bigger, older families.

During his examination, Nesvorný noted several small, new asteroid clumps within the known big families and among the swarms of background, non-family asteroids.

From clump to very young cluster

One of these small clumps was a 39-body cluster associated with the asteroid 832 Karin, itself a member of the large Koronis family. Nesvorný surmised the clump resulted from the parent asteroid's collisional breakup at perihelion (the point in its orbit closest to the Sun).

"It became immediately clear that if it was a true family, it must be very young," Nesvorný recalls. "A small cluster of asteroids like this would survive for a hundred million years, no more," he adds. Such a young asteroid family represents a treasure trove of impact science for asteroid researchers. Nesvorný pondered whether the orbital histories of the 39 Karin cluster asteroids could be tracked back in time to ascertain whether they all matched up at some point in the recent past.

The Karin cluster members lie near the middle of the asteroid belt, their orbits are inclined from the orbital plane only slightly, and they don't reside near any strong orbital resonances with the major planets. Thus, few perturbations exist to complicate tracking their orbital trajectories back in time. To accomplish this backward progression, Nesvorný looked for a convergence at some point in the past of two angles that describe

the orientation of the asteroids' orbits in space. These two angles evolve with different but nearly constant speeds for the individual asteroid orbits, however, due to gravitational perturbations from the planets.

Immediately after a parent asteroid breaks up, its fragments move out on their own orbits around the Sun that are all oriented more or less like that of the original parent. After enough time has passed, the family members' orbits are all oriented in random directions. The time in the past when the orbital orientations were co-aligned indicates the family's age — the time elapsed since the fateful disruptive collision.

From his reverse orbital integrations, Nesvorný found the time elapsed since the collision that formed the Karin cluster was a remarkably short 5.8 million years. Never before has an asteroid family been dated so precisely, and this one was born just yesterday, astronomically speaking. "I couldn't believe my eyes!" says Nesvorný.

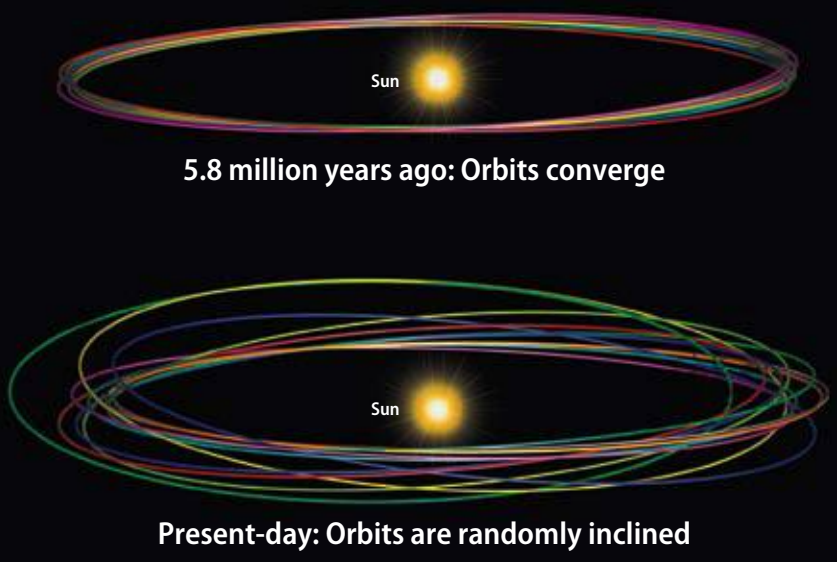
The implications of Nesvorný's finding poured forth in short order. The Karin cluster's relative youth and well-defined age make this little family and its member asteroids a wonderful natural laboratory for better understanding the physics of catastrophic disruption and the geology of asteroids.

Asteroid 832 Karin, at 10.6 miles (17.1 kilometers) across, is the largest remnant of a once larger parent asteroid. The next-largest fragment in the cluster is asteroid 13907 1998 XE_{13}. Its diameter is about 3.4 miles (5.4 km). The remaining cluster members have even smaller sizes. The Karin cluster's size distribution is a hallmark of impact disruption.

When monoliths collide

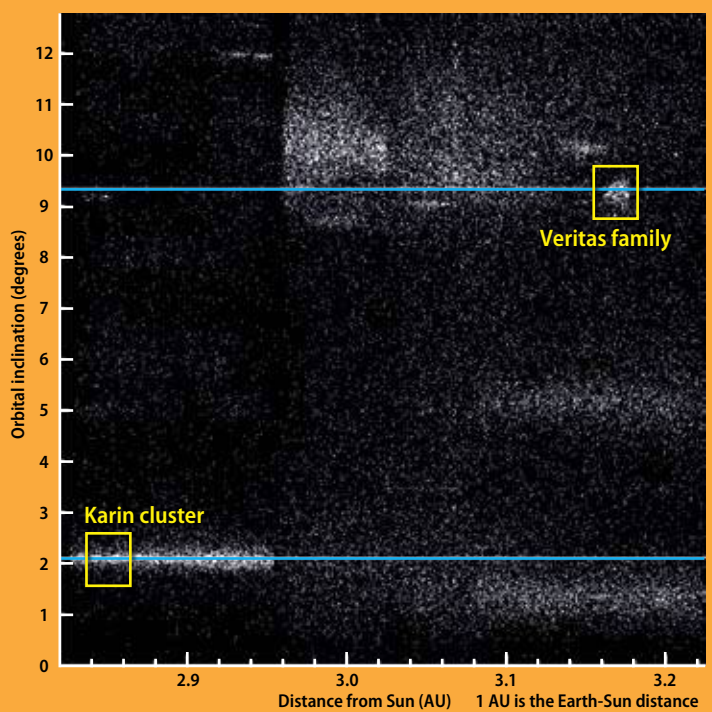
Nesvorný employed smooth-particle hydrodynamics (SPH) computer simulations to model the heating, shocks, and fractures in rocky materials during impacts in order to track the outcomes of a range of asteroid-to-asteroid impact events. His goal was to match the Karin cluster members' observed sizes with his model, thus learning more about the circumstances of the collision that formed the little family. Out of more than 100 simulated impact events, the model that matched best indicates the Karin cluster's parent body spanned about 20 miles (33 km). Some 5.8 million years ago, another 3½-mile-wide (5.75 km) asteroid, coasting along in its own orbit, crossed paths with Karin's parent at a closing speed of about

Then and now



KARIN CLUSTER ORBITS converge 5.8 million years ago when astronomers integrate the orbits of 39 cluster members in reverse, as this illustration shows. Today, their orbits are oriented randomly due to planetary perturbations. But 5.8 million years ago, the Karin fragments had similar orbits. *ASTRONOMY:* ROEN KELLY, AFTER DAVID NESVORNÝ (SWRI)

A tale of two dust bands



IRAS DUST BANDS share the same orbital inclination as young asteroid families. The Karin cluster dust band is inclined 2.1° and lies in the main belt's inner region, while the Veritas cluster dust band is inclined 9.3° and resides in the outer portion of the main belt. *ASTRONOMY:* ROEN KELLY, AFTER DAVID NESVORÝ (SWRI)

Spectra reveal effects of space weathering

1 Parent asteroid

Impacting object

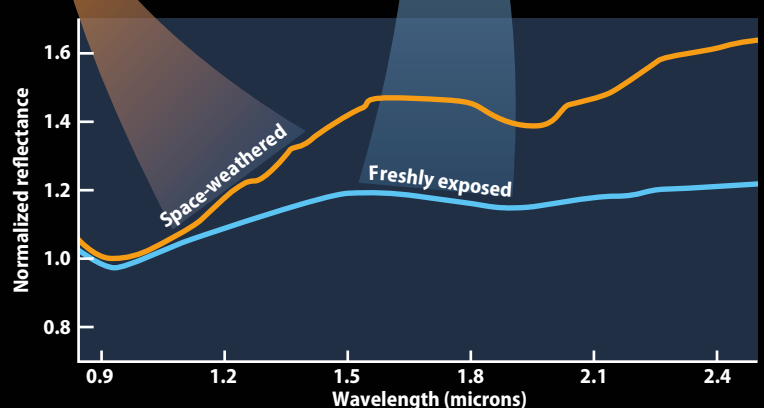
SPACE ROCKS are on collision courses as they travel around the Sun in the main asteroid belt.

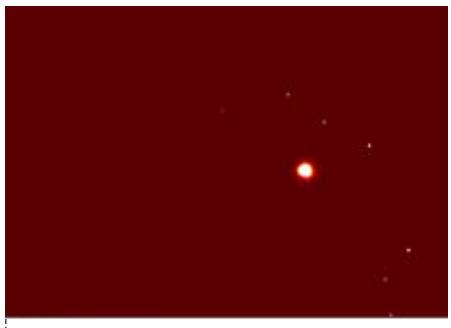
2 Collision

BODIES COLLIDE, forming a family of rocky fragments and sending an influx of helium-3-laden interplanetary dust to Earth.

3 Asteroid after impact

SPACE WEATHERING shows up in the spectra of the Karin asteroid family. A spectrum of the family's largest fragment, 832 Karin, reveals a "red" space-weathered exterior and a "blue" exposed interior face. *ASTRONOMY:* ROEN KELLY, AFTER DAVID NESVORNÝ (SWRI)





ASTEROID 832 KARIN is the largest member of the Karin cluster and has a diameter of about 10 miles (17 km). Astronomers used the European Southern Observatory's Very Large Telescope to acquire this 5-second exposure July 15, 2003. The image spans about 8". W. J. MERLINE (SWRI)/P. M. TAMBLYN (SWRI)

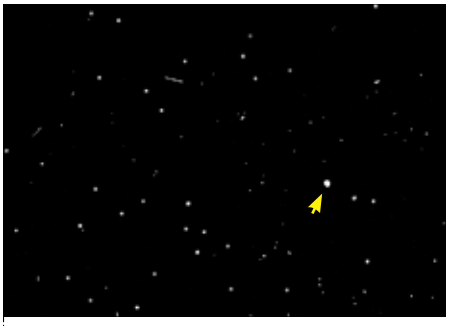
14,400 miles per hour (23,175 km/h). The violent impact shattered the parent asteroid, dispersed the fragments into new orbits, and the Karin cluster was born.

These models suggest the Karin parent asteroid may have been a monolithic body with no fractures (or at least a body that was only lightly fractured inside). Karin's parent asteroid was itself a fragment of the much larger Koronis family. Similar SPH models of the breakup of larger asteroid family parents like Koronis, which resulted in the creation of the Koronis family some 2–3 billion years ago, suggest many of the family's larger members are rubble piles that have coalesced due to gravity's attractive force, rather than solid, coherent fragments.

In the case of the Karin cluster, in contrast, Nesvorný has verified the larger remnant bodies created in the simulated impact are all single, monolith fragments of the original parent. The largest fragment, corresponding to asteroid 832 Karin, is composed of the back third or so of the parent asteroid; the front two-thirds was blasted away in the cluster-forming impact. One side of the largest fragment, therefore, might preserve a portion of the parent's outer surface, while the other side exposes rock from its previously hidden deep interior.

Red asteroid, blue asteroid

This result appears to match yet another observed characteristic of the asteroid Karin. Recent research suggests young S-type asteroids — the most common type of rocky asteroid in the inner main belt — like Karin may have "bluer" reflection spectra than do older, redder S-type asteroids. Fresh S-type asteroid spectra more closely resemble the



ASTEROID 41307 (1999 XA_{149}) (arrow) is the smallest Karin cluster member imaged in high resolution. This unprocessed HST image also contains detector artifacts.

W. J. MERLINE (SWRI)/P. M. TAMBLYN (SWRI)

spectra of ordinary chondrite meteorites — the most common type of stony meteorite. Exposure to radiation and micrometeoroid impacts in space must weather the surfaces of S-type asteroids over time, causing them to become darker and redder and look less like fresh ordinary chondrite material.

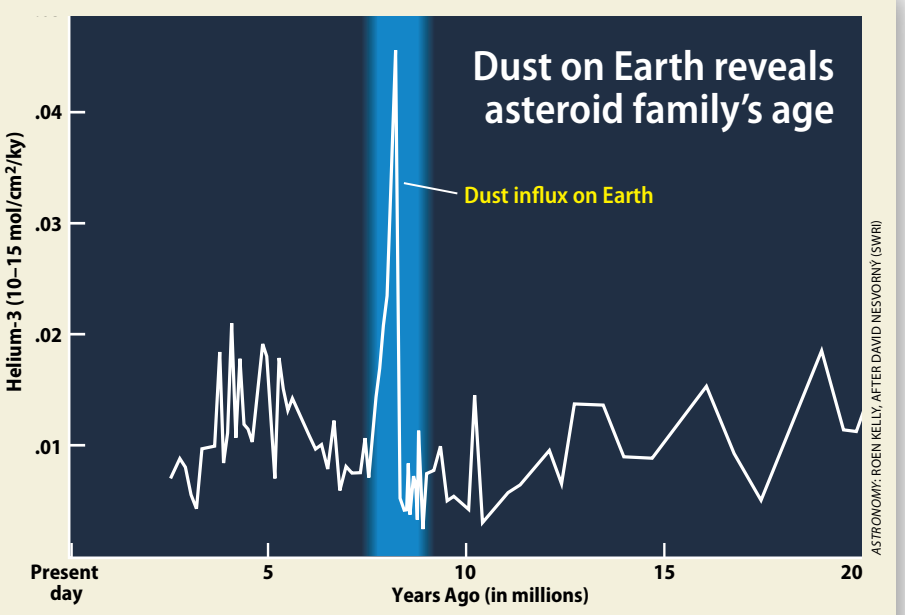
Motivated by Nesvorný's determination of the very young age of the Karin cluster, Takanori Sasaki of the University of Tokyo and his colleagues observed Karin. The group used Japan's 27-foot (8.2 meters) Subaru optical-infrared telescope, located atop Mauna Kea in Hawaii, in September 2003 to obtain a series of near-infrared spectroscopic observations of Karin to test this idea.

The astronomers found that Karin, indeed, has a bluer near-infrared spectrum than the other, older members of the Koronis family. What's more, Sasaki's team found that one side of Karin is bluer than the other side and suggested the two sides have different histories of exposure to the radiation and micrometeoroid environment of space, called space weathering. This result agrees with Nesvorný's impact models, giving asteroid scientists a clock by which to measure the rate of space weathering (see "Seeing red," June 2006).

The proof is in the dust bands

Might the catastrophic disruption of a 20-mile-diameter (33 km) asteroid in the recent past have produced dusty debris still visible today? Nesvorný recalled the IRAS dust bands. Embedded within the Koronis family Dermott thought was the source of the 2.1° bands, Nesvorný wondered if, instead, the much smaller and younger Karin breakup was responsible. This would clash with Dermott's model but support the model of Mark Sykes and Rick Greenberg, both of the University of Arizona. In 1986, they suggested the IRAS dust bands are transient features of the zodiacal cloud produced only recently by the collisional breakup of asteroids several miles wide. The Karin cluster's small size, young age, and apparent association with the 2.1° bands seem to fit the bill.

The clincher came when Nesvorný found the 8.3-million-year-old Veritas family, whose orbital inclinations match up with the 10° bands' ecliptic latitude. This solved the long-standing problem of the less-than-satisfactory fit from the big Eos family, and chalked up yet another place in the history books for the Karin cluster's role in advancing our understanding of asteroids.



VERITAS FAMILY'S AGE FOUND

The formation of the Veritas asteroid family 8.3 million years ago coincides with a flurry of interplanetary dust on Earth.

Using the same method of tracking orbital trajectories back in time that led to the discovery of the Karin cluster's young age, David Nesvorný of the Southwest Research Institute in Boulder, Colorado, found the Veritas family is only slightly older, at 8.3 million years. The Veritas family is located in the outer main belt and is composed of C-class asteroids — dark asteroids thought to be related to carbon- and water-rich carbonaceous chondrite meteorites. This larger asteroid family formed from the breakup of a roughly 93-mile-diameter (150 kilometers) parent body.

Ken Farley of Caltech, David Vokrouhlický of Charles University Prague in the Czech Republic, and Bill Bottke of the Southwest Research Institute, along with Nesvorný, have found compelling independent evidence for the Veritas family's age. The disruption coincides with a significant increase in the accretion rate of interplanetary dust particles on Earth as recorded by amounts of helium-3 — an isotope of helium that is a component of the solar wind — found in deep-sea sediments dating from the late Miocene period, 8.2 million years ago.

HELIUM-3 CAPTURED in interplanetary dust particles fell to Earth in abundance some 8.3 million years ago.

Helium-3 is implanted in interplanetary dust particles as they spiral in from the asteroid belt toward the inner solar system under the effects of solar-wind drag forces like the Poynting-Robertson effect. Dust particles that encounter Earth at low enough speeds can enter the atmosphere slowly enough such that they never melt and release their helium-3. Many of these particles settle to the deep ocean sediments and carry the implanted helium-3 with them, thus becoming a measure of the dust accretion rate on Earth.

The coincidence of a large increase in the flux of interplanetary dust on Earth just after the formation of the Veritas family highlights the very real connection between our planet and its interplanetary surroundings. — *D. D.*

ONLINE EXTRA Learn more about space weathering at www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

OCTOBER 07

Planet action moves to the morning sky

As Jupiter and Uranus slide

into western twilight, Neptune becomes the sole evening planet, observable only with binoculars or a telescope. Mars rises around midnight, but the real show occurs when bright planets congregate in the predawn sky.

The morning highlight is a spectacular conjunction in Leo the Lion between brilliant Venus and Saturn.

44 Venus, Saturn rule the morning
49 See the Orionid meteor shower
49 Catch Marius Hills shadows
50 When to view the planets
50 Mars passes M35
50 View a comet in Coma Berenices
51 Pallas slips between Uranus and Neptune

Visible to the naked eye
Visible with binoculars
Visible with a telescope

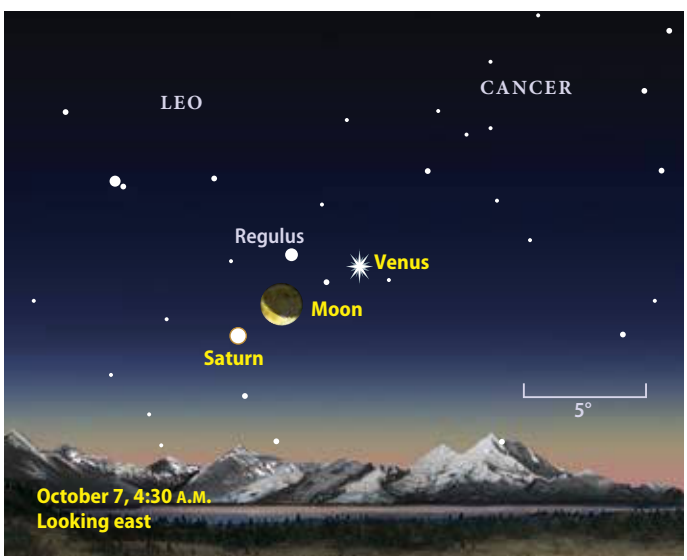
Mercury makes a brief and poor appearance for Northern Hemisphere observers. The planet, which lies far south of the ecliptic, hugs the western horizon right after sunset. Mercury slips between Earth and the Sun (inferior conjunction) October 23.

Jupiter gleams ever lower in the southwest as the month progresses, and the planet's best views occur in twilight. Jupiter hovers 20° above the horizon an hour after sunset October 1. But by month's end, the giant planet stands only 12° high an hour after the Sun goes down. It won't be long before Jupiter exits the evening sky.

By October 31, Jupiter sets before 9 P.M. local daylight time. That night, the solar system's largest world also has faded to magnitude –1.9.

— *Continued on page 49*

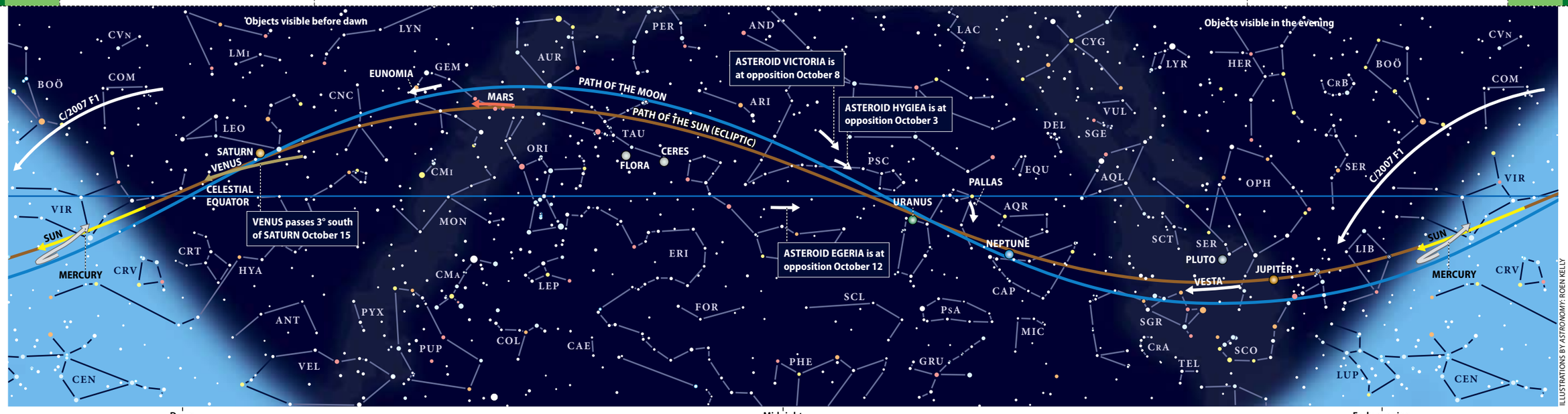
THE CRESCENT MOON, its night side dimly aglow from earthshine, encountered the Pleiades star cluster April 19. October opens with a gibbous Moon near the cluster. MOHAMMAD TAHER PILEVAR



VENUS, Saturn, Regulus, and the waning Moon partake in a picture-perfect arrangement low in the east before dawn October 7. *ASTRONOMY:* ROEN KELLY

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



Dawn — Midnight — Early evening

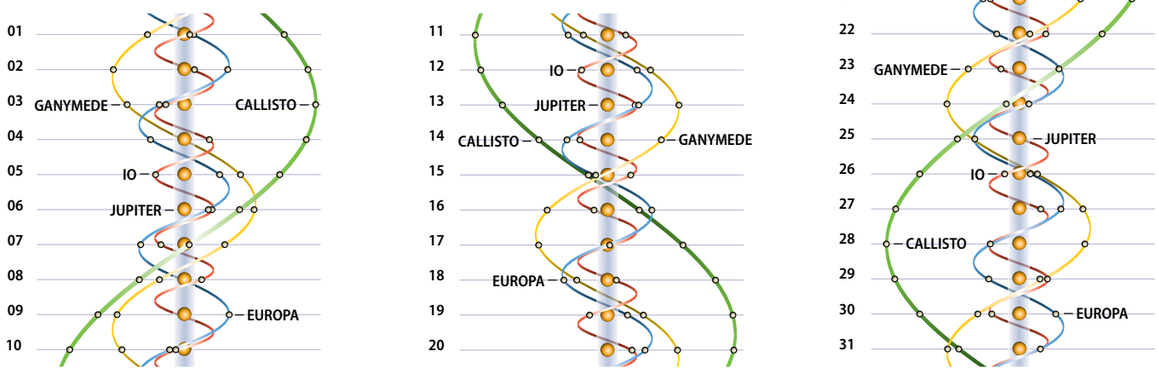
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

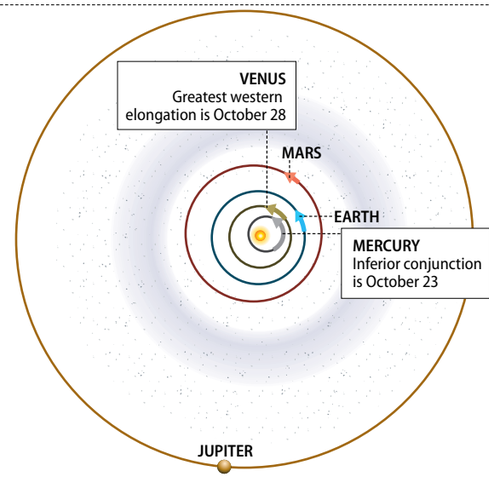
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	VENUS	VENUS	MARS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	October 1	October 1	October 31	October 1	October 31	October 15	October 15	October 15	October 15	October 15
Magnitude	0.0	−4.7	−4.5	−0.1	−0.6	−1.9	0.8	5.8	7.9	14.0
Angular size	7.0"	34.2"	23.5"	9.7"	12.1"	34.1"	16.8"	3.7"	2.3"	0.1"
Illumination	57%	33%	52%	87%	90%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.965	0.488	0.710	0.967	0.776	5.781	9.906	19.277	29.562	31.756
Distance (AU) from Sun	0.443	0.724	0.720	1.468	1.507	5.275	9.246	20.094	30.044	31.357
Right ascension (2000.0)	12h59.3m	9h43.1m	11h26.1m	6h03.5m	6h47.2m	17h00.9m	10h28.8m	23h07.1m	21h26.9m	17h45.7m
Declination (2000.0)	−15°19'	10°07'	4°03'	23°22'	23°55'	−22°26'	11°02'	−6°32'	−15°20'	−16°52'

Jupiter's moons

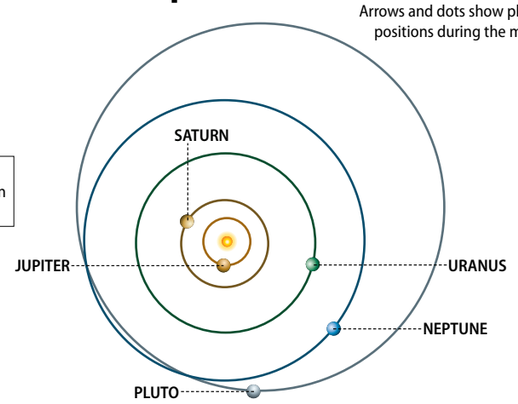
Dots display positions of Galilean satellites at 10 P.M. EDT on date shown. South is at top to match the view through a telescope.





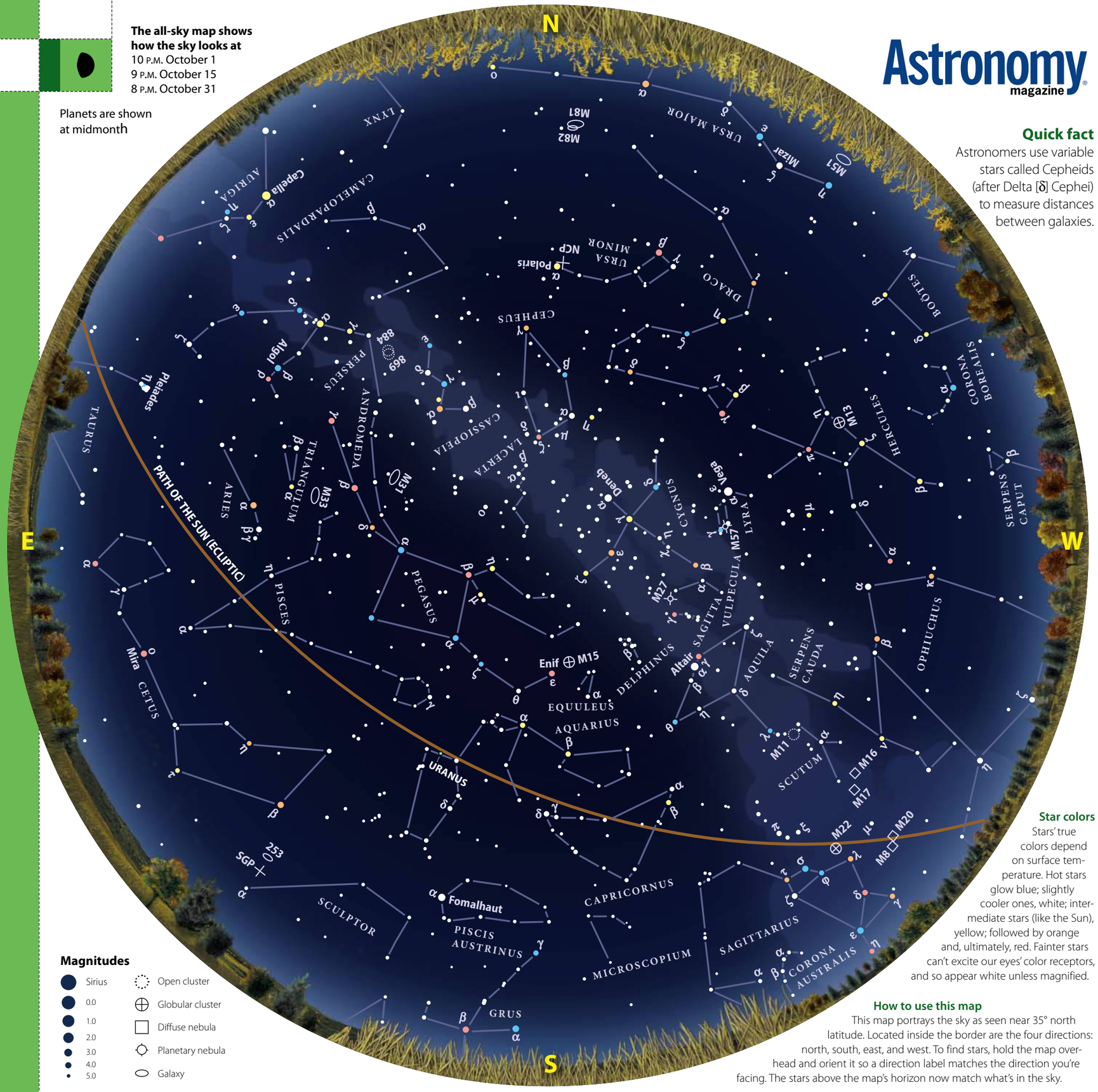
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth



Magnitudes

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0
- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

Astronomy magazine

Quick fact
Astronomers use variable stars called Cepheids (after Delta [δ] Cephei) to measure distances between galaxies.

Star colors
Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

NOTABLE OBSERVING DATE:
October 21, when the Orionid meteor shower peaks

october 07

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	[01]	[02]	[03]	[04]	[05]	[06]
[07]	[08]	[09]	[10]	[11]	[12]	[13]
[14]	[15]	[16]	[17]	[18]	[19]	[20]
[21]	[22]	[23]	[24]	[25]	[26]	[27]
[28]	[29]	[30]	[31]			

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

02 The Moon passes 5° north of Mars, 4 P.M. EDT

03 Last Quarter Moon occurs at 6:06 A.M. EDT

06 The Moon passes 3° north of Venus, 11 P.M. EDT

07 The Moon passes 0.2° north of Regulus, 3 A.M. EDT

The Moon passes 1.3° south of Saturn, noon EDT

09 Draconid meteor shower peaks

Venus passes 3° south of Regulus, 7 A.M. EDT

11 New Moon occurs at 1:01 A.M. EDT

12 The Moon passes 1.3° south of Mercury, 9 P.M. EDT

13 The Moon is at apogee (252,582 miles from Earth), 5:51 A.M. EDT

15 Venus passes 3° south of Saturn, 10 A.M. EDT

15 The Moon passes 0.5° south of Antares, 11 A.M. EDT

16 The Moon passes 5° south of Jupiter, 2 A.M. EDT

19 First Quarter Moon occurs at 4:33 A.M. EDT

20 The Moon passes 1.3° south of Neptune, 11 P.M. EDT

21 **Orionid meteor shower peaks**

23 Mercury is in inferior conjunction, 8 P.M. EDT

26 Full Moon occurs at 12:52 A.M. EDT

The Moon is at perigee (221,676 miles from Earth), 7:51 A.M. EDT

28 Venus is at greatest western elongation (46°), 11 A.M. EDT

30 The Moon passes 3° north of Mars, 3 P.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

— *Continued from page 44*

Throughout the month, Jupiter courses through the constellation Ophiuchus. The planet gleams 7° northeast of Antares, the brightest star of Scorpius the Scorpion.

Jupiter's moons dance on either side of the planet's disk. Their near-circular orbits are edge-on from our vantage point, so they appear to yo-yo east and west of the planet. The four brightest moons — Io, Europa, Ganymede, and Callisto — are easy targets for small scopes.

Distant **Pluto** is poorly placed for observation this month. The dwarf planet sets with the stars of Sagittarius in late evening.

But the eighth planet, **Neptune**, is easily available. The ice giant glows at magnitude 7.8 and lies in Capricornus the Sea Goat. If you know where to look, you can find this distant world with 7x50 binoculars. The ideal is to mount the binoculars on a tripod. That way, you can hold a red flashlight and refer to a star chart while zeroing in on your quarry.

Look in northeast Capricornus to find Deneb Algiedi and Nashira (Delta [δ] and Gamma [γ] Capricorni), which lie 1.75° apart. To the west (right) of fainter Nashira lies an even dimmer star, Iota (ι) Cap. Shining at magnitude 4.3, the star is an easy naked-eye target only on a clear, moonless night. You'll find Neptune a little less than 2° northeast of Iota.

This region lies due south and at an altitude of well over

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*

WATCH THE ORIONID METEOR SHOWER

This year's annual Orionid meteor shower coincides with New Moon. Be sure to catch the shower this month.

The Orionids appear to radiate from a spot in northeastern Orion near its border with Gemini. The radiant rises before midnight and stands high in the south by 4 A.M., a full 2 hours before dawn. The shower begins October 2 and ends November 7.

Meteor rates start and end with a trickle, but they achieve a substantial peak October 21. In 1993 and 1998, the Orionids displayed enhanced rates 3 to 4 days before the usual peak, so it's worth watching the shower over a week's time centered on the date of maximum. Rates can reach 20 meteors per hour, and occasionally more.

The predawn hours offer the best viewing. These meteors are among the fastest of all shower meteors, striking Earth's upper atmosphere at 41 miles per second. Many leave persistent trains — glowing tubes of ionized gas created as the incoming dust particles burn up.

Orionid meteors derive from debris left behind by Comet 1P/Halley during its many passages through the inner solar system. Earth's orbit intersects this debris trail in two places. One spot gives rise to this fine autumn shower. The other location is the source of May's Eta Aquarid shower.

ASTRONOMY: ROEN KELLY

THE ORIONID METEOR SHOWER should provide a couple of dozen fast-moving meteors per hour when it peaks October 21.

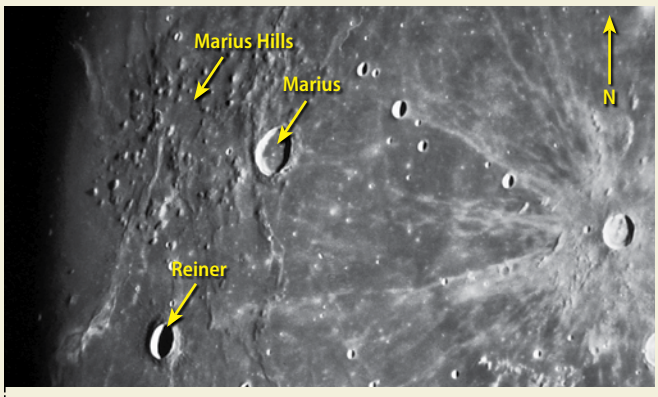
SEE MARIUS HILLS' VOLCANIC CONES

Eleven days following New Moon (October 22), the Sun rises on the Marius Hills, a collection of some 300 volcanic cones spanning about 120 miles. You can find the Marius Hills just north of the Moon's equator in the vast basin of Oceanus Procellarum and south of Aristarchus Crater.

Scientists speculate a large area of gas-rich magma built the steep-sided cones. Later, lava flowing from the nearby rilles filled the lowlands around them.

Many years later, an asteroid or comet slammed into the area and created Marius Crater, which blotted out some preexisting cones. Lava oozed into the crater's cracked floor and flooded its interior. Long after the Moon's surface solidified, another interplanetary rock blasted out Reiner Crater nearby.

The Hills' lumpy surface really stands out when the Sun angle is low. Look early in the evening of October 23, when the shadows are especially long. Return a few hours later before retiring for the night. How much have the Hills' numerous triangular shadows receded?



CONSOLIDATED LUNAR ATLAS/LPI/UA

A RISING SUN highlights the Marius Hills' 300 volcanic cones. Look for their triangular shadows October 23.

/// WHEN TO VIEW THE PLANETS

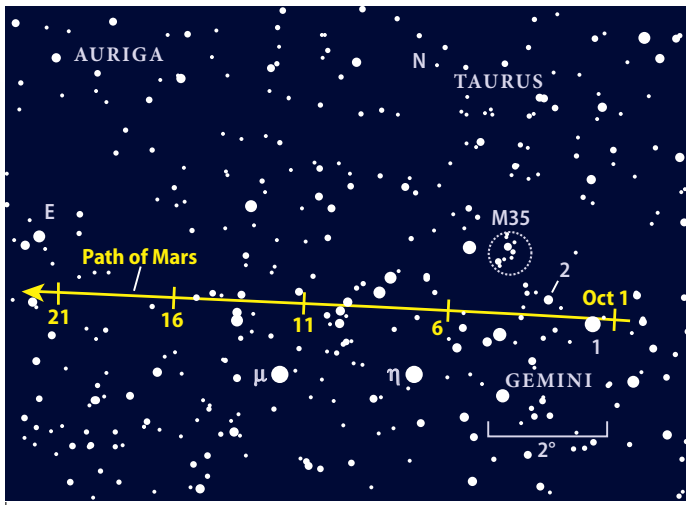
EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Mars (east)	Venus (east)
Jupiter (southwest)	Uranus (southwest)	Mars (south)
Uranus (south)	Neptune (southwest)	Saturn (east)
Neptune (south)		

30° around 10 P.M. local daylight time. Neptune hardly moves relative to the background stars this month because it's reaching the western end of its retrograde loop. The distant giant is stationary in right ascension October 31 and sets after midnight.

Uranus takes up residence in the next constellation east; the planet is due south nearly 2 hours after Neptune. Uranus, however, is much brighter at magnitude 5.7. The planet reached opposition in September, and it remains well placed for observing.

Because Uranus is so much brighter than Neptune, it's much easier to find in binoculars. Find the Great Square of Pegasus, high in the southern sky. Draw an imaginary line down the square's right side until you reach a bright star. This is Fomalhaut in Piscis Austrinus. Look for Uranus midway between the square's lower star and Fomalhaut. It lies near the 4.2-magnitude star Iota Aquarii.

As October opens, Uranus lies 1.4° west of Phi (ϕ) Aquarii. The planet's retrograde motion carries it 2.2° west of the star by October 31. High magnification — 150 times or more — will reveal its tiny 3.6"-diameter disk in a telescope.

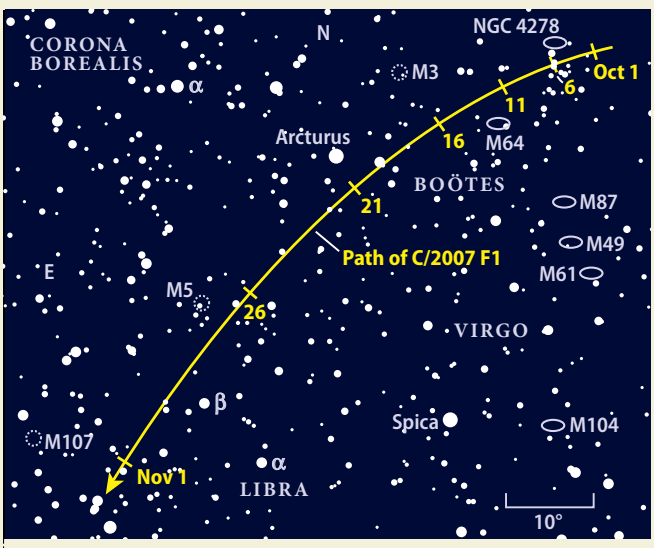


MARS OBSERVING ramps up this month as the Red Planet skims past open cluster M35 in Gemini. Mars will be at its best by year's end. The planet remains a good observing target through February 2008. *ASTRONOMY:* ROEN KELLY

In early October, bright orange **Mars** rises before midnight. On October 3, the Red Planet rises with a Last Quarter Moon and stands within a degree — less than 2 Moon-diameters — of Gemini's fine open cluster, M35. Take a long look at this wonderful arrangement through binoculars.

Between October 7 and 12, Mars passes north of Eta (η) and Mu (μ) Geminorum. The planet's eastward motion slows daily as Earth closes and prepares to overtake it.

Mars is bright, reaching magnitude –0.6 by month's end. The Red Planet's brightness and color beautifully complement



C/2007 F1 (LONEOS) courses through Coma Berenices and passes bright Arcturus this month. Compare the comet to the many galaxies along its path. *ASTRONOMY:* ROEN KELLY

AN EVENING COMET RUNS THROUGH COMA

Rapidly brightening comets always bring a smile to an amateur astronomer's face. A moving object that changes shape, structure, and magnitude invigorates all observing sessions.

Astronomers found C/2007 F1 (LONEOS) March 19. It starts the month at magnitude 11, but astronomers expect it to reach magnitude 7 by month's end.

LONEOS, which lies low in the northwest an hour after sunset, is gliding through Coma Berenices. The comet's unusual name is an acronym that stems from the Lowell Observatory Near-Earth Object Search, a project that scans the skies for asteroids and comets.

Comets shine mostly from sunlight scattering off the dust they shed. This dust forms a coma that completely obscures the tiny, solid nucleus from astronomers' view. This diffuse glow often mimics the appearance of elliptical galaxies.

On October 8, compare the comet to the 11th-magnitude galaxy NGC 4278. Your best views will be from a dark country sky with no major population centers to the northwest.

Once the Moon enters the scene after the 12th, you'll have to wait until the 28th before LONEOS again appears in a dark sky. Plan your observing time to avoid the bright Hunter's Moon.

magnitude 0.4 Betelgeuse, nearly 20° away in Orion's shoulder. The increasing apparent size of Mars' disk — 12" by October 31 — reveals its distinctly gibbous phase. The Red Planet is a fine telescopic object from now through February 2008. "Mars season" peaks in late December, when the planet reaches its greatest apparent size and glows at its brightest. This will be our best view of the Red Planet until 2016.

If you view Mars around midnight in early October, the hemisphere facing Earth will include Syrtis Major, the planet's darkest and most recognizable feature. Mars rotates once every 24.5 hours. As a result, martian features seen at the same time each night appear to rotate backward out of sight. Syrtis Major gradually will spin into view as the night progresses later in the month.

Plan to awaken early October 7 — a spectacular view awaits you in the eastern sky. Shortly after 4:30 A.M., Venus, Mars, Saturn, the Moon and the bright star Regulus in Leo rise in the east, all within a 6° circle.

Venus is bright, shining at magnitude –4.7. A telescope reveals a 38-percent-lit disk — an interesting contrast to the 13-percent-illuminated crescent Moon. Try viewing Venus through a scope with your right eye, and the Moon with your unaided left eye.

Venus lies less than 3° southwest of 1st-magnitude Regulus, Leo's brightest star. Saturn lies 6° east of Venus, while the crescent Moon stands less than 2° west of Saturn. By dawn, around 6:30 A.M., the four objects have climbed high in the east. Be ready to answer questions from coworkers.

The Moon leaves the scene the following morning, but beginning October 9, Venus, Saturn, and Regulus huddle within a 5° circle for 4 days. **Saturn** shines at magnitude 0.8. Saturn's rings now angle only 8° to our line of sight. The rings will be edge-on to us in 2009. Their long axis spans 39", while the rings' short axis spans just 5". Look on the rings' western side for the planet's shadow.

Venus is less than 3° due south of Regulus October 9, and 2.9° south of Saturn October 15. Venus' sunlit portion rises to 50 percent when it reaches greatest elongation (46.5°) October 28. Venus is now moving away from Earth and spans just 23" by month's end.

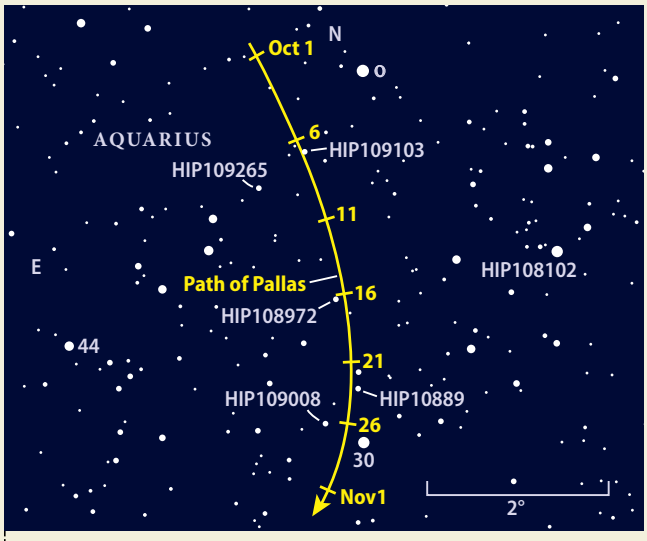
NEPTUNE AND URANUS FRAME PALLAS

Like a pebble settling toward the bottom of a pond, asteroid 2 Pallas sinks through Aquarius' Water Jar and slides deeper into the southern skies. Its movement from night to night against the background stars makes it clear Pallas is part of our solar system.

With a 3-inch scope, you can monitor the asteroid's shift with a quick sketch at the eyepiece. (Watch video tips for sketching your observations at www.astronomy.com/videos.) Plot a handful of stars near Pallas' position, then return in a night or two to see which one of the 9th-magnitude dots moved.

A couple of hours after sunset, Aquarius floats a third of the way up the southern sky. Uranus and Neptune are in the neighborhood, too. These huge planets — each more than 100 times Pallas' 300-mile width — appear as tiny disks through the telescope. Pallas, however, remains only a literal dot for amateur astronomers.

The discovery of the first asteroids — 1 Ceres in 1801 and Pallas in 1802 — came 20 years after Sir William Herschel discovered Uranus with a 6-inch scope. Initially hailed as planets, the asteroids were eventually acknowledged to belong to a new class of objects. Similarly, and somewhat begrudgingly, astronomers have come to view Pluto as the brightest member of a class of icy objects orbiting the Sun beyond Neptune.



ASTRONOMY: ROEN KELLY

PALLAS, THE SECOND ASTEROID discovered, continues its swing through Aquarius. Look for this 9th-magnitude space rock near 30 Aquarii at month's end.

JOHN SACHS

ON JULY 1, back when they were in the evening sky, Venus slipped less than 1° south of Saturn. The star Regulus (top left) and a splash of sparkling fireworks frame the planets. This month, look for Venus and Saturn in the east before dawn.

STREET-CORNER ASTRONOMY

One night, sidewalk astronomer Jeffrey Jacobs offered a free look at the Moon. But would skeptical New Yorkers accept the gift? /// **BY PHIL SCOTT**

"Come see the Moon!"

Thursday evening. In New York City they call it "the new Friday," meaning the night when everyone gets an early start on the weekend. Jeffrey Jacobs sets up his 8-inch Newtonian telescope on the northwest corner of Bleecker Street and 6th Avenue in Greenwich Village. Here, the high-rises sit low, and Jacobs focuses his telescope on the Moon, now making its debut in the east. Then, he violates an unwritten New York City law and starts talking to strangers.

"Come see the Moon," he says in a raspy voice. "Come see the Moon."

People try to ignore him. A man walks past, holding his daughter's hand.

"Come take a look at the Moon," Jacobs beckons. The man pauses, suspicious, and tries to keep going. But his daughter springs on her tippy-toes like excited kids do.

"Without touching the scope, just move up and slowly look with one eye," Jacobs says. "What do you see?"

"It looks like it could fall," she says. "I have a book about the sky."

"That's great," Jacobs says. He's age 61, genteel and dignified with his wire-rimmed glasses and dark jacket.

"She got a book about the stars and the sky for her birthday," Dad explains.

"I just turned five," she says.

"Tell him thank you," Dad says.

"Thank you," she says.

"You're very welcome," Jacobs replies, and hands her a leaflet about the sky he brought with him.

"Come see the Moon," he says, adjusting the scope. A few people look at him but keep walking. "Come see the Moon." A man in a gray coat stops.

"What's your purpose?" Gray Coat asks.

"It's a public service," Jacobs explains. "Sidewalk astronomy. We're looking at the Moon tonight," he says. Gray Coat steps up to the eyepiece and looks intently. "This is the best I've ever seen it. Why do we see only one side?"

"The gravitational pull of the Earth over billions of years has stopped the Moon from spinning," Jacobs explains. "It's dancing with us, and we're telling it we want to look at its face all the time."

He re-centers the telescope. "Look at the crater near the top." Gray Coat concentrates on the eyepiece. "It's named Tycho, after the Danish astronomer Tycho Brahe," Jacobs says. "The wall measures thousands of feet high." Gray Coat stares. "See the rays emanating from the crater? They're formed from glass beads. Some of the rays measure 1,000 miles long. That's the distance from New York to Chicago."

A red-haired man wearing a red jacket jabbers obliviously into his cell phone. He stops in front of the telescope, waiting for the light to turn green. "Come look at the Moon," Jacobs tells him. Red Jacket turns around, a little stunned. "Okay," he says, dialing another number.

He closes the phone and steps up to the eyepiece. "Wow," he says. "Wow … wow. Why are you doing this?"

"Just as a public service," Jacobs says.

"Thank you very much. It's funny, during the blackout we slept on the roof and I said, 'When was the last time you saw a sky full of stars in Manhattan?'" He opens up the phone to make another call. "I saw the Moon. Through a telescope. What? Seriously."

"Hey, didn't I see you two years ago in the East Village, on Houston?" A thin, dark-haired man asks. "You were showing

Phil Scott *is a writer in New York. He is author of, among other books,* Hemingway's Hurricane *(McGraw-Hill, 2005).*

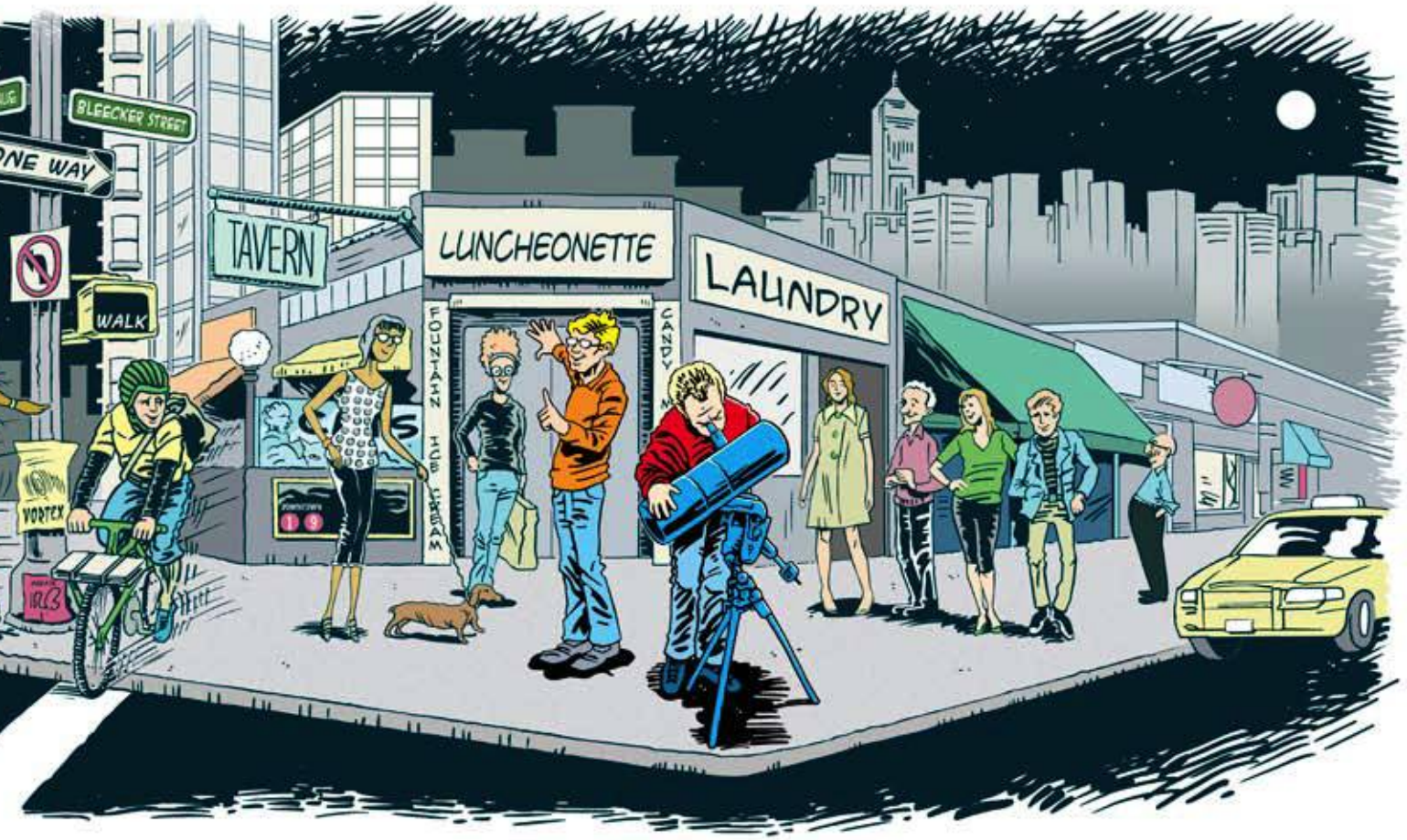
HOW TO ENJOY THE MOON

Urban astronomy is not an oxymoron. Even in major metropolitan centers like New York City, where light pollution casts a pall over the sky every night, you can still explore the sky with a small telescope (in the 2- to 3-inch-wide range) or binoculars.

The favorite target of urban astronomers, the Moon, is big, bright, and easy to find. You can see fine details on the lunar surface with a small telescope or binoculars. With a Moon map, you can spend hours exploring our luminous satellite.

This article is based on material presented in *Astronomy* columnist Phil Harrington's "Urban skies" series on the web. To read the articles, go to: www.astronomy.com/urbanskies. —*Daniel Pendick*

THE MOON'S Tycho Crater, with its 1,000-mile-long (1,600 km) rays, is visible through a small telescope ADAM STUART



Jupiter then."

"Yes, that was me." They shake hands. "Tonight it's the Moon. Take a look."

He does. A woman with red hair and a knee-length coat walks up.

"Can I look? Cool." She puts her eye on the lens. "Whoa! How cool!"

"Yes it is, and it's yours," Jacobs says.

"Oh. Wow. Wow! It looks so close."

"It's about 240,000 miles away."

"Can you see more the higher you are? I used to live in Santa Fe and I'd see maybe 15 shooting stars a night," she says.

"Were they in August or November?"

"I guess November."

"They're called the Leonids." He explains the Leonid meteor shower and hands her the leaflet.

"One more question. Is the Moon in waning gibbous or waxing gibbous phase?"

"Good question! It's waxing."

"Thank you!" She walks away backward, then whirls. "Goodbye!"

Another woman strides by with a yellow Labrador retriever on a leash. The lab wears a pumpkin-colored bandana tied around its neck that vaguely matches the woman's baseball cap and jacket. The dog sniffs around the scope's mount.

"What is that?"

"A telescope. We're looking at the Moon." She peers down the tube. "Lean over here, look into the eyepiece."

"Wow!"

"That's the right noise."

"Wow! What's so different about it tonight?"

"Just that I'm here with a high-powered telescope."

"Only in New York could you come outside and see a telescope and an astronomer on the corner of the street," she says, the dog pulling her away to sniff at trees. "Thanks for doing that. That's very great."

"What are you looking at?" a young man in a dark ski cap asks.

"We're looking at the Moon."

"Does it cost anything?" Jacobs shakes his head and re-centers the scope.

"Nothing in this city is free."

"This is."

"Cool." He looks. "Amazing! Quick question. I'm looking for Greenwich Avenue and Perry."

"Go straight up here. Turn left at the old women's prison."

"There's a women's prison here?"

"Was. It's a park now."

"What prompted you to do this?"

Jacobs tells him about John Dobson. A one-time monk, Dobson, 92, built his first telescope in 1956 out of a junk-store lens and an eyepiece salvaged from Zeiss binoculars. Then he turned it on the third-quarter Moon and thought, "Everybody's got to see this." So Dobson carted his telescope to the sidewalk, and handed out plans for building cheap scopes using trashed cardboard tubes, hand-ground mirrors, and the simple "alt-azimuth" mount that's now named after him.

"He challenged other astronomers to take their scopes out of their backyards and onto the street corner, and be a public service," Jacobs says. "To talk about the universe and remind people where we live. Because what we see every day is nothing like where we really live."

Where we really live is not this small intersection in the Village. Where we really live is on a blue-and-white planet, orbited by a pitted gray moon, orbiting a yellow star, which orbits a spiral galaxy inside a vast universe. On some nights, sidewalk astronomers come out with the Moon to walk in John Dobson's shoes and remind people that the place where they really live might even be as big and fascinating as New York City on a Thursday night.

ONLINE EXTRA To learn more about what you can observe in light-polluted urban skies, go to www.astronomy.com/toc.

Mars in high def

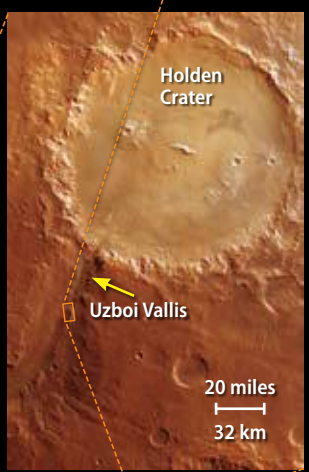
The Red Planet explodes with detail under Mars Reconnaissance Orbiter's amazing cameras. /// BY RICHARD TALCOTT

Percival Lowell — eat your heart out. More than a century ago, the Boston Brahmin believed canals etched the surface of Mars, bringing water to a parched and dying civilization. The illusion survived, at least in the public's mind, until NASA's Mariner 4 spacecraft flew past Mars in 1965 and returned images of a heavily cratered world.

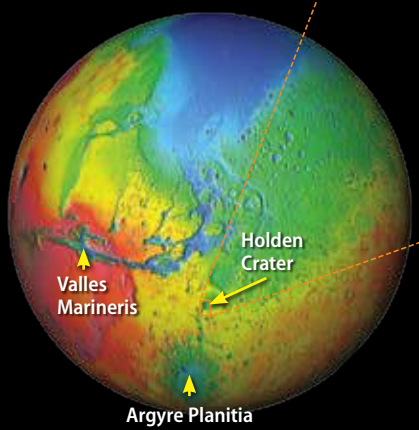
In the 42 years since Mariner 4, dozens of spacecraft have flown past, orbited, or landed on the Red Planet. With each new probe, planetary scientists see more and learn more. But they've never seen anything quite like the images returned by Mars Reconnaissance Orbiter (MRO).

MRO's High Resolution Imaging Science Experiment (HiRISE) can image features as small as about 10 inches (25 centimeters) across from its 180-mile-high (300 kilometers) orbit. Most of the images are so huge (think in gigapixels) we can't reproduce them at full size and resolution.

Here, we present a tiny piece of a HiRISE image at full resolution (far right), so you can see what scientists see. This false-color view shows Uzboi Vallis, a channel that drains into Holden Crater, where it forms a large delta. The channel exposes ancient, fractured bedrock likely created some 3.9 billion years ago. The range of colors indicates a diverse composition, although scientists don't know yet its precise makeup.

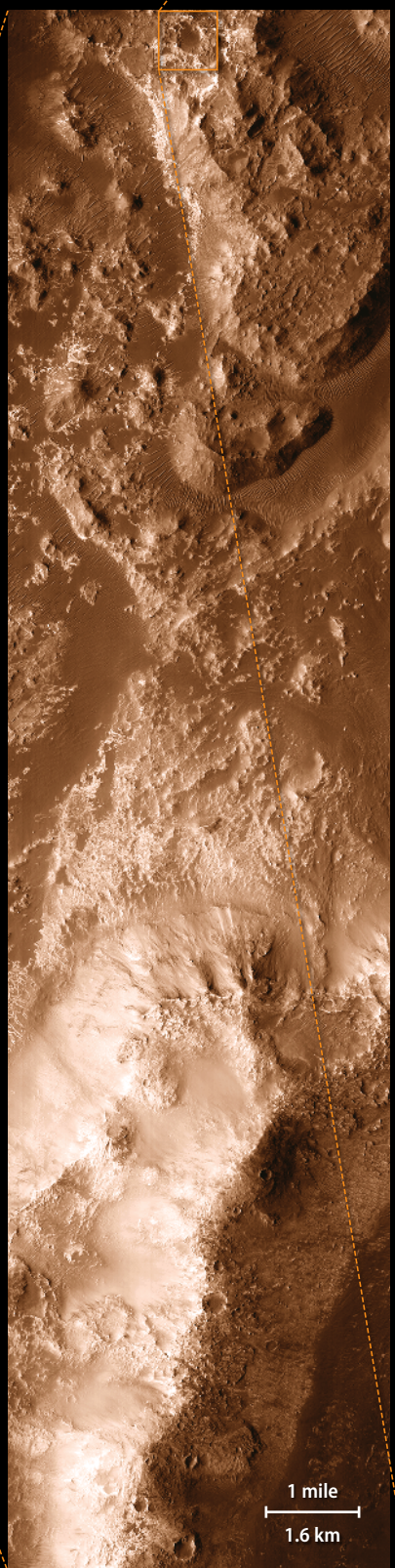


▲ **UZBOI VALLIS** drains into 96-mile-wide (154 km) Holden Crater. Planetary scientists think at least two ancient lakes existed in Holden, which is also a candidate landing site for NASA's Mars Science Laboratory in 2010. MARS EXPRESS IMAGE BY ESA/DLR/FU BERLIN (G. NEUKUM)

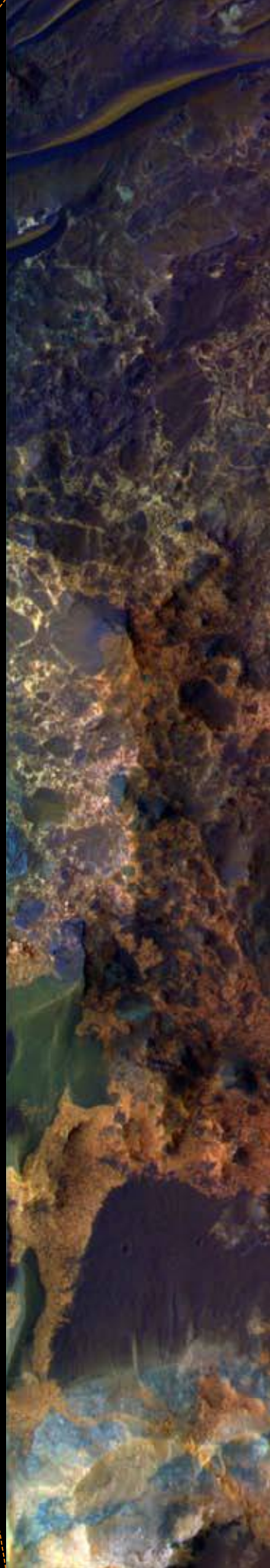


▲ **HOLDEN CRATER** lies southeast of Valles Marineris and due north of Argyre Planitia. It sits on what may have been a vast waterway extending from the south polar cap to the northern lowlands.

ASTRONOMY: ROEN KELLY, AFTER USGS



▶ **FRACTURED BEDROCK** and megabreccia (sedimentary deposits with large, angular rock fragments) exposed in Uzboi Vallis likely formed during the solar system's late heavy bombardment some 3.9 billion years ago. HiRISE IMAGE BY NASA/JPL/UNIVERSITY OF ARIZONA



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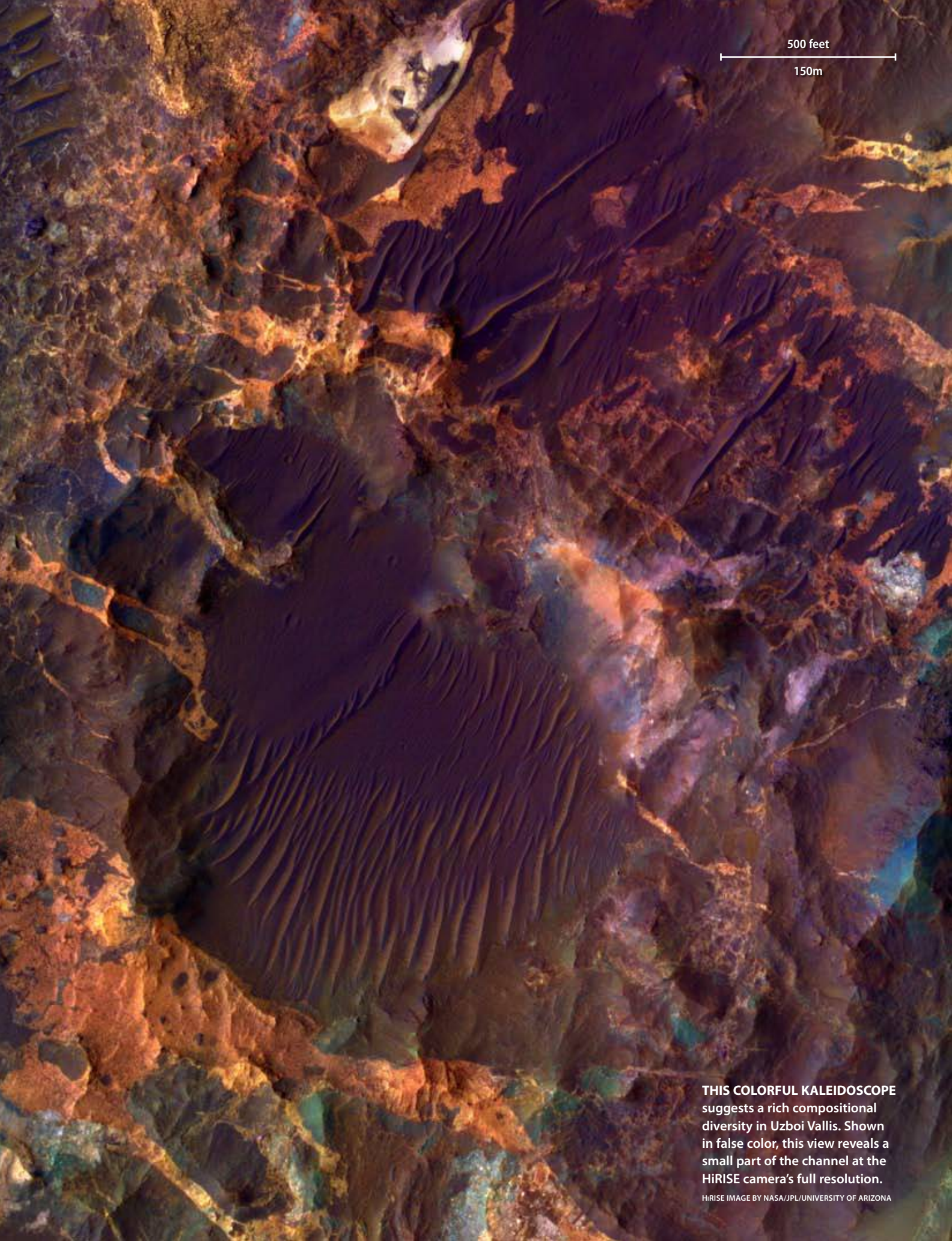
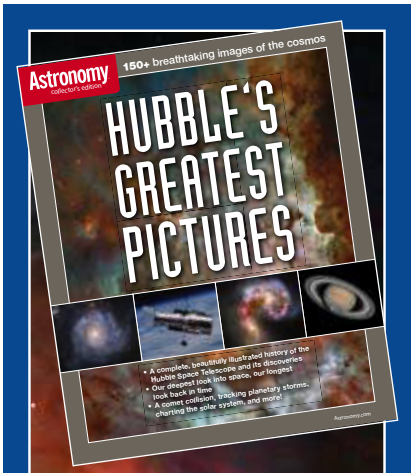


THIS COLORFUL KALEIDOSCOPE suggests a rich compositional diversity in Uzboi Vallis. Shown in false color, this view reveals a small part of the channel at the HiRISE camera's full resolution.

HiRISE IMAGE BY NASA/JPL/UNIVERSITY OF ARIZONA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Intricate gas clouds and sparkling stars await you. /// **BY RICHARD JAKIEL**

Observe autumn's best nebulae

Few objects in the sky are as beautiful

or photogenic as bright emission nebulae. Whether you're observing the "Pillars of Creation" in the Eagle Nebula (M16) in Serpens, the "Cosmic Tornado" in Sagittarius' Lagoon Nebula (M8), or the brilliant stellar factory in the center of the Orion Nebula (M42), these objects delight the eye.

You'll find many of these spectacular targets in the Sagittarius and Orion sections of the Milky Way. So, at first glance, those nebulae found in the autumn Milky Way stretching from southern Cepheus to Perseus seem pale in comparison. Although the latter lie off the beaten path, they should rank highly on your "must see" list.

The Cepheus giants

Although nearly as large as the nearby North America Nebula (NGC 7000) in Cygnus, observers often overlook **IC 1396**, which spans an impressive 3°. Astronomers believe this region is older and less complex than the Orion Nebula. IC 1396 forms the southern rim of the "Cepheus Bubble," a 10°-wide ring of faint nebulae formed about 1.7 million years ago by a titanic supernova explosion.

Near IC 1396's center sits the large, splashy open star cluster Trumpler 37, which spans nearly 1°. Only 3 million years old, it is one of the youngest clusters in the galaxy. Through an 8-inch scope, you'll see more than 50 hot, blue stars. A multiple-star system much like the Trapezium in the center of M42 — lies at the cluster's center. Designated HD 206267, or STF 2816, the 6th-magnitude primary star has two 8th-magnitude blue companions lying 11.7" and 19.9" away.

To observe this object, start from Herschel's Garnet Star (Mu [μ] Cephei) and star-hop to Trumpler 37 within IC 1396. From there, use your widest-field eyepiece equipped with a nebula filter to sweep the region. Both the star cluster and STF 2816 are easy targets through any telescope.

Far more challenging is the **Elephant Trunk Nebula** (IC 1396A), an unusual structure often visible in long-exposure images of the region. This dark globule with a bright rim resembles the "star pillars" of the Eagle Nebula (M16) and the "worm tunnels" of the Rosette Nebula (NGC 2237–9). I have seen only parts of the Elephant Trunk's southern rim through a 24-inch reflector at my astronomy club's dark-sky site. Luckily, it's not too difficult to image using today's CCD cameras, even through a 3-inch scope.

Even more obscure is the **NGC 7822/ Cederblad 214** region, which lies near the Cassiopeia border. Ced 214 (the inner region) is a bright shell of dust and gas surrounding open star cluster Berkeley 59, while NGC 7822 (the northern component) is a broad, filamentary structure. NGC 7822 formed as the result of strong stellar winds from Be 59's bright stars, which compress the region's gas and dust.

I can see both portions easily through my 4.8-inch rich-field refractor under a dark sky. When I insert a nebula filter, the central wisps of Ced 214 are clearly visible, while the graceful arc of NGC 7822 reminds me of a smaller, slightly fainter version of the famous California Nebula

IC 1396 IN CEPHEUS is a huge cloud of glowing hydrogen crossed with dust lanes. Within its borders, you'll find the elusive Elephant Trunk Nebula. For best results viewing IC 1396, use a nebula filter and an eyepiece that gives a wide field of view. CHUCK VAUGHN

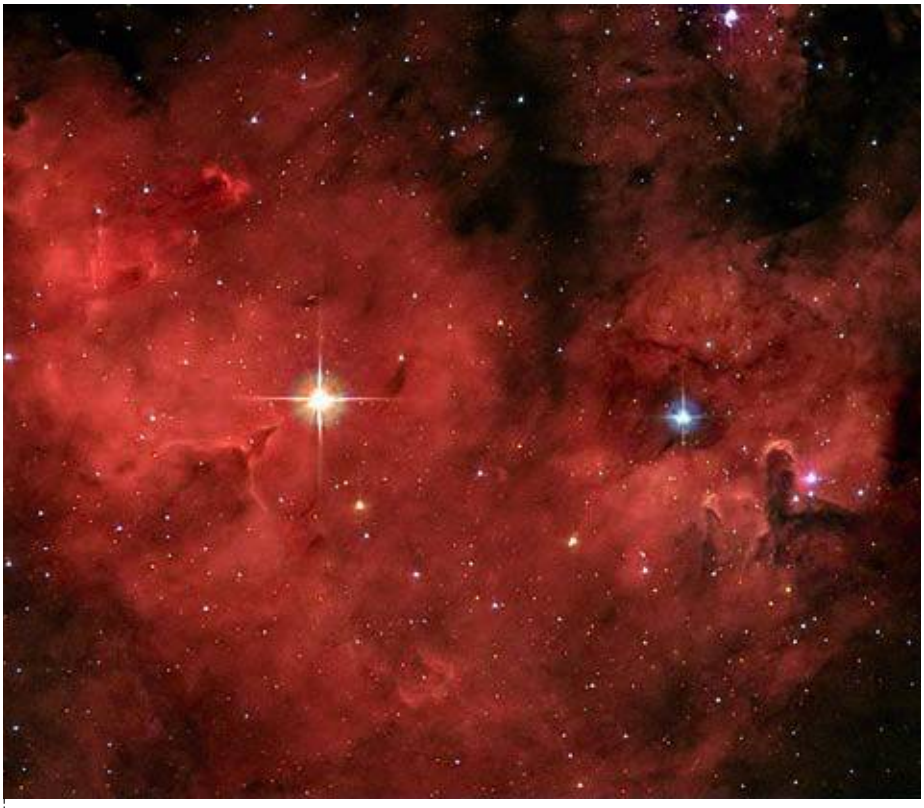
THE BUBBLE NEBULA (NGC 7635) lies 0.5° southwest of open cluster M52. Seeing the entire bubble through your eyepiece is difficult — you'll need a large telescope and a dark site. WOLFGANG PROMPER

(NGC 1499) in Perseus. Larger telescopes will help you make out the fainter members of Be 59 and the delicate wisps and knots in the nebulosity.

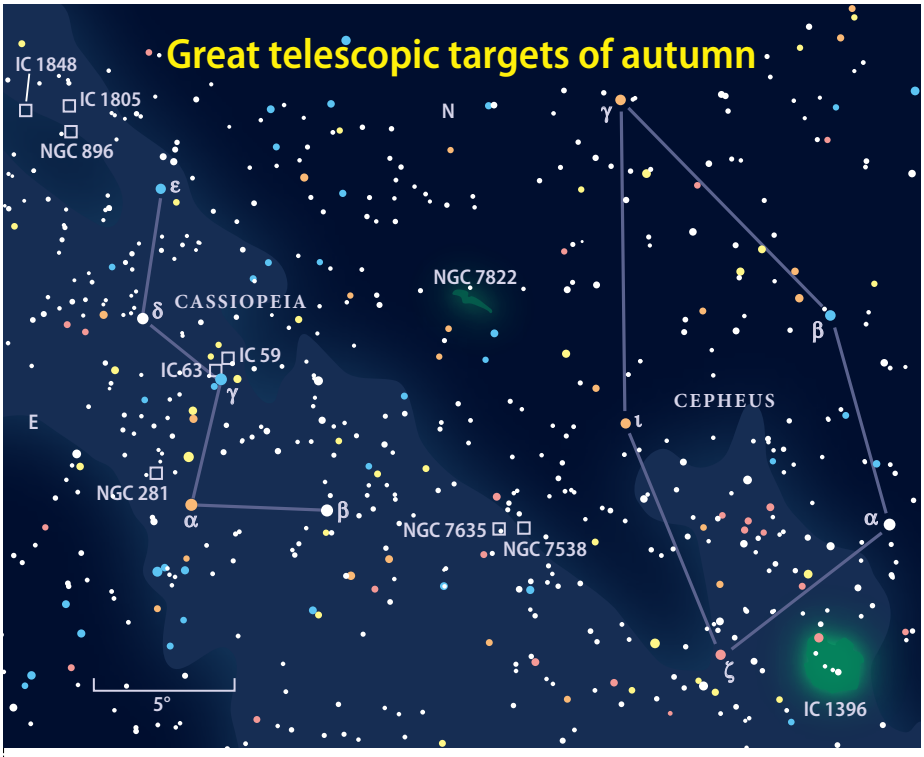
Small and compact

Not all the emission nebulae in this region are sprawling giants. Some of the brightest will fit easily in the field of view of even a large-aperture telescope. Perhaps this region's most famous object is the **Bubble Nebula** (NGC 7635). Because it lies only 30' southwest of open cluster M52, the Bubble Nebula is an easy object to find by star-hopping. It measures 16' by 6'; the "bubble," however, is much smaller — a sphere only about 100" in diameter.

The ionized bubble is a cavity produced by the pressure of stellar wind from a strangely offset 8th-magnitude star. A 6-inch telescope equipped with a nebula filter will reveal a bright nebulous "knot" or "arc" around the central star, plus some of the



CEDERBLAD 214 in Cepheus glows from nebulosity and newborn stars. Just north of Ced 214 lies the fainter nebula NGC 7822 (not shown). The stars surrounded by Ced 214 form open star cluster Berkeley 59. For best results, use a nebula filter. WOLFGANG PROMPER



CASSIOPEIA AND CEPHEUS contain many nebulae. Some of these treasures are faint, so find a dark observing site and let your eyes dark-adapt. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

/// AUTUMN NEBULAE AND OTHER CELESTIAL TREATS

Object	Right ascension (2000.0)	Declination (2000.0)	Size/separation
IC 1396	21h39m	57°30'	170' by 140'
NGC 7538	23h14m	61°31'	10' by 6'
The Bubble Nebula (NGC 7635)	23h21m	61°12'	16' by 6'
NGC 7822	0h01m	68°34'	72' by 20'
Cederblad 214	0h03m	67°13'	50' by 40'
The Pacman Nebula (NGC 281)	0h53m	56°38'	28' by 21'
IC 59	0h57m	61°09'	13' by 7'
IC 63	0h59m	60°54'	10' by 3'
NGC 896	2h27m	62°05'	21'
IC 1795	2h27m	62°05'	21'
The Heart Nebula (IC 1805)	2h33m	61°30'	100' by 80'
The Soul Nebula (IC 1848)	2h54m	60°24'	100' by 53'
IC 1871	3h03m	60°28'	4' by 3.5'

outlying wisps. To see the elusive bubble in its entirety, however, requires a large instrument under dark, moonless skies.

Just a short hop away is compact star-forming region **NGC 7538**. By most amateur standards, this ranks as an obscure object, yet it is a hotbed of astronomical research with more references cited than all the other objects on my list combined. NGC 7538 lies 1⅓° due west of M52 and often shows up in wide-angle photos of the region. The central area is a diminutive version of the Orion Nebula. Although photogenic like its neighbor NGC 7635, NGC 7538 shows little through the eyepiece. Using my 12-inch scope, I could glimpse only a small star cluster washed with the faint glow of nebulosity.

Perhaps the strangest-named emission nebula is the **Pacman Nebula** (NGC 281). Bearing a resemblance to the famous video-game icon, its real shape results from overlapping bright and dark clouds of gas and dust. You can spot NGC 281 through a 6-inch scope. Look about 2° east of Schedar (Alpha [α] Cassiopeiae). Perhaps the most prominent feature is IC 1590, a compact open cluster located in the nebula's heart.

THE PACMAN NEBULA (NGC 281) has this unusual visual structure because of overlapping clouds of glowing hydrogen and dark dust. TARYN SIMON/ADAM BLOCK/NOAO/AURA/NSF

Only 3.5 million years old, several dozen stars concentrate in a region only a few arcminutes across. This also includes multiple-star system ADS 719, which lies in the cluster's center. The closest component sits only 1.4" from the 8th-magnitude primary.

Considerably more challenging to observe are the dark star-forming clouds called Bok globules scattered across this nebula. The most distinct is an irregular inky spot located about 2.5' east-northeast from IC 1590's core. Use approximately 100x and an Oxygen III (OIII) filter to maximize the contrast.

Less than 0.5° from Cih (Gamma [γ] Cassiopeiae) lie two little oddball nebulae — **IC 59** and **IC 63**. Both are comet-shaped clouds and part of the much larger HII (ionized hydrogen) region Sharpless 185. Because it lies closer to Cih, IC 63 reemits light more strongly than IC 59. Both are tricky objects to observe because Cih lies so close. Make sure the star lies outside your eyepiece's field of view before trying to hunt them down.

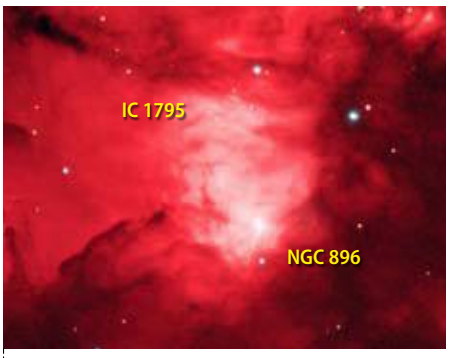
Cassiopeia's heart and soul

Along the eastern fringes of Cassiopeia lies a broad complex of star clusters and bright nebulae known to many astrophotographers as the "Heart and Soul" nebulae. More than 7,500 light-years distant, they sit within our galaxy's Perseus Arm. The westernmost HII region is the **Heart Nebula** (IC 1805), named for its remarkable resemblance to that human organ.

In its center, numerous O and B stars of open cluster Melotte 15 illuminate the neb-

Richard Jakiel *has observed the deep sky for 30 years. He recently coauthored* Galaxies and How to Observe Them *(Springer, 2006).*

THE HEART NEBULA (IC 1805) in Cassiopeia combines glowing gas, dark dust clouds, and the star cluster Melotte 15 at the nebula's center. PIERRE TREMBLAY



NGC 896 forms the brightest knot within the northwestern section of the Heart Nebula (IC 1805). An adjoining, slightly fainter knot is IC 1795. SEAN AND RENEE STECKER/ ADAM BLOCK/NOAO/AURA/NSF

ulosity. Their stellar winds sculpt the gas and dust into fantastic spires and "elephant trunks." Smaller semi-detached nebulae lie along both the western and eastern margins of the main region. **IC 1795** and **NGC 896** form bright knots along the northwest extension, while the small, bright open cluster NGC 1027 sits off the eastern flank.

The **Soul Nebula** (IC 1848), also called the Baby Nebula, forms the complex's eastern half. It has a rough rectangular shape, comprising two shells separated by a broad dust lane. Open star clusters form the core of each shell — the sparse cluster Collinder 32 in the western section, and the much larger double cluster Collinder 33/34 in the east. Off the eastern margin lies IC 1871, a small nebulous knot you can glimpse with 6-inch and larger telescopes.

THE SOUL NEBULA (IC 1848) surrounds a recently formed star cluster. The nebula's hydrogen atoms absorb ultraviolet light from the stars and reemit it as visible light with a reddish hue. JIM BURNELL

IC 59 AND IC 63 are bright sections of Sharpless 185, a glowing cloud near 2nd-magnitude Gamma (γ) Cassiopeiae. Use high magnification to reveal these clouds' comet-like shapes, and place Gamma Cas outside the field of view. TOM BUSH/JOHN FOX/ADAM BLOCK/NOAO/AURA/NSF

Both the Heart Nebula and the Soul Nebula are large and faint. As with many large nebulae, aperture isn't as important as having dark skies and high-contrast fields of view, along with nebula filters.

Under dark skies, I saw both nebulae distinctly through my 4.8-inch (120mm) refractor. By contrast, they faded to near-invisibility in the narrow fields of large-aperture telescopes. Sweeping back and forth across the field will help you observe these large, elusive nebulae.

My list of bright and interesting nebulae in the autumn sky is far from comprehensive. You'll find many other fascinating objects along the "Cepheus Bubble" and the broad region west of open cluster M52 in Cassiopeia. With a little planning and a clear dark sky, some of these objects may become your favorites, too.

ONLINE EXTRA Download an Autostar tour of these objects for your Meade go-to telescope at www.astronomy.com/toc.

ASK ASTRO

This month:
- Will Pluto ever collide with Neptune or Uranus?
- How do astronomers measure stellar wind?
- What is a comet?
- What is a solar prominence?

CROSSING ORBITS

Q: Will Pluto ever collide with Neptune or Uranus?

— **PAUL PERALES,** WEST HOLLYWOOD, CALIFORNIA

A: If the planets remain in their current orbits, no.

It's true that Pluto's elongated orbit carries it closer to the Sun than Neptune, and then farther away from the Sun than Neptune. However, crossing orbits does not imply these planets will collide. Here's why:

As Pluto travels in its orbit, Neptune's gravity causes small "course corrections." These slight corrections maintain several tens of degrees of angular separation between the two planets.

Pluto's orbital period shares a 3:2 relationship with Neptune's. Neptune goes around the Sun three times for every two Pluto orbits. This orbital resonance causes the two planets to move in a dance-like pattern. Moreover, during the part of Pluto's orbit that lies interior to Neptune's, Pluto is also near its farthest distance above the solar system's mean plane. This ensures that, when Pluto is near perihelion, the Pluto-Neptune distance (as well as the Pluto-Uranus distance) remains large — well over 10 times the average distance between Earth and the Sun. — **RENU MALHOTRA,** LUNAR AND PLANETARY INSTITUTE, UNIVERSITY OF ARIZONA, TUCSON

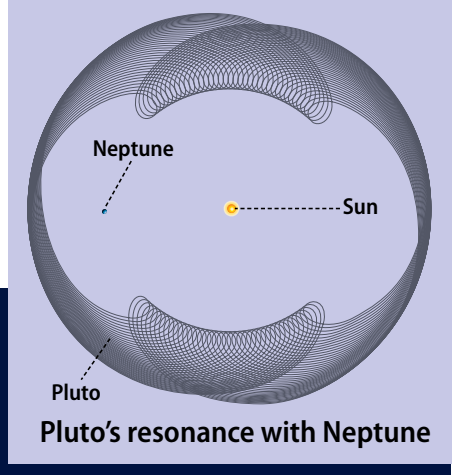
MEASURING WIND

Q: How do astronomers measure the speed of dust and gas carried away by stars' stellar winds? — **LUCAS LEWELLEN,** LIBERTY, MISSOURI

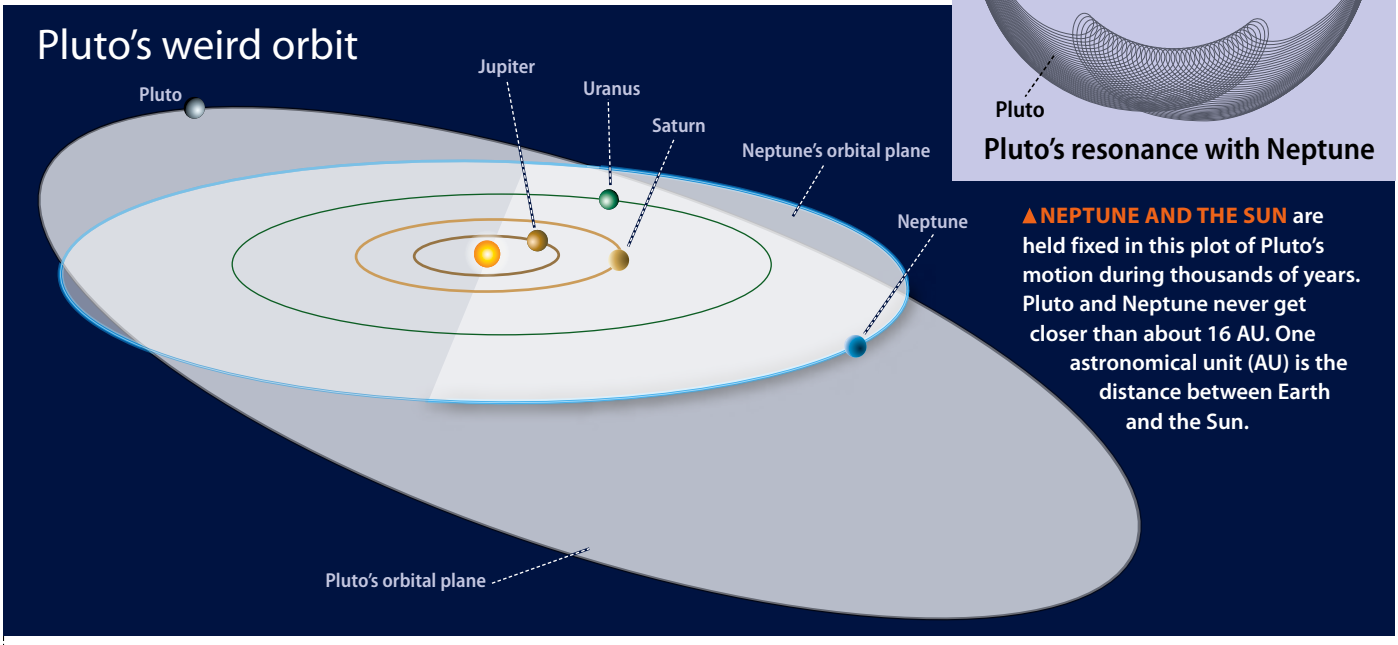
A: Astronomers detect stellar winds by examining a star's spectrum.

A spectrometer is an instrument that separates starlight into its wavelengths. The atoms in a stellar wind absorb light at certain wavelengths, which produces dark absorption lines in the star's spectrum.

By studying the amount of absorption, astronomers can infer the wind's total mass-loss rate. By measuring the precise absorption wavelengths, astronomers can infer the wind's speed. Measuring the wind's speed relies on the Doppler effect: For a given absorption line, faster winds moving toward us from the star will absorb light at shorter wavelengths than slower winds. — **BRIAN WOOD,** UNIVERSITY OF COLORADO, BOULDER



Pluto's resonance with Neptune



▲ NEPTUNE AND THE SUN are held fixed in this plot of Pluto's motion during thousands of years. Pluto and Neptune never get closer than about 16 AU. One astronomical unit (AU) is the distance between Earth and the Sun.

▲ PLUTO TRACES out an elongated orbit around the Sun. While Pluto moves inside Neptune's orbit, the two bodies won't collide because they're never in the same place at the same time. ILLUSTRATIONS: *ASTRONOMY*: JAY SMITH, AFTER RENU MALHOTRA (UNIV. OF ARIZONA)

DIRTY SNOWBALL

Q: What is a comet?

— **JOHN SCHNEIDER,** MERTON, WISCONSIN

A: Comets are dark, solid bodies measuring a few miles across.

Astronomers describe them as "dirty snowballs" because they are mixtures of dust and frozen gases, like water and carbon dioxide.

Scientists call a comet's solid part its nucleus. Some of the nucleus' icy material — perhaps less than 1 percent — evaporates as the comet nears the Sun. This creates an envelope of gas and dust that enshrouds the nucleus, preventing astronomers from seeing it up close. This envelope, which scientists call the coma, may extend 620,000 miles (1,000,000 kilometers). Swept back by the solar wind and the radiation pressure of sunlight, this material forms a comet's tails.

Typically, comets have two tails. The gas, or ion, tail is a stream of ionized gas atoms that glows faintly bluish as it interacts with sunlight. It points directly away from the Sun. Dust ejected from the comet reflects sunlight, and it usually creates a broader, brighter, curving, yellowish tail.

A comet's tail can span distances greater than that between Earth and the Sun. That such a small amount of material creates visible features so large has led some to describe comets as "the closest thing to nothing anything can be and still be something." — **FRANCIS REDDY,** ASSOCIATE EDITOR

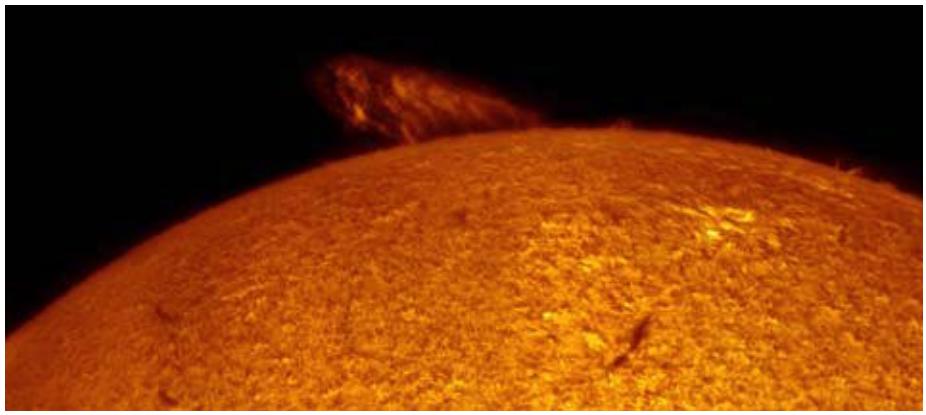
IN THE KNOW

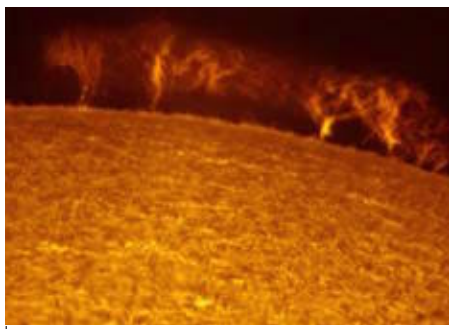
ORBITAL RESONANCE
Two bodies exert a periodic gravitational influence on one another, like Pluto and Neptune.

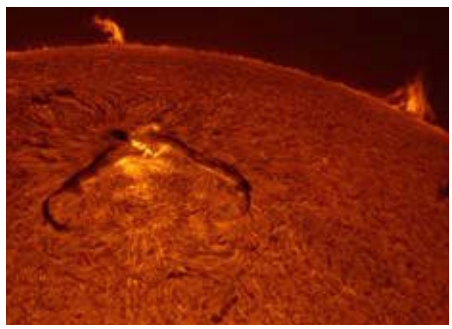
SPECTRUM
Light spread into its component wavelengths, much like a rainbow. A star's spectrum contains information about its makeup, motion, and environment.

PROMINENCE
A large loop of plasma anchored into the photosphere that arches above the solar surface, held by magnetic fields.

NUCLEUS
The central region of an atom or galaxy; the solid body of a comet.







SOLAR PROMINENCES appear as wispy sprites hovering above the Sun's boiling surface. Prominences are streams of plasma lifted off the solar surface by the Sun's magnetic field. Most prominences extend thousands of kilometers. GARY PALMER

ERUPTING PLASMA

Q: What is a solar prominence, and what equipment do you need to photograph one?

— **AMBER BARTON,** EL PASO, TEXAS

A: Solar prominences are dense clouds of ionized gas (plasma).

Located in the solar corona, where temperatures are the hottest, these clouds are relatively cooler and appear as dark filaments against the Sun's bright disk. Prominences are observed or photographed using a Hydrogen-alpha filter. Such filters reveal prominences projecting beyond the Sun's edge, or limb.

Magnetic forces at the Sun's surface influence prominences and make them unpredictable. Solar prominences can appear in minutes, and can last for days or vanish in mere seconds.

I use a Hydrogen-alpha solar telescope mounted on a tripod, along with a point-and-shoot digital camera, to capture these elusive phenomena. I center the lens over the eyepiece and release the shutter. Prominences are dimmer than the photosphere or solar disk, so I overexpose the brighter photosphere by leaving the camera's shutter open longer. — **GARY PALMER,** SOLAR PHOTOGRAPHER, LOS ANGELES

COMING NEXT MONTH ...
How does *Astronomy*'s "Planets this month" foldout map work? Post your comments about this question online at www.astronomy.com/forums.

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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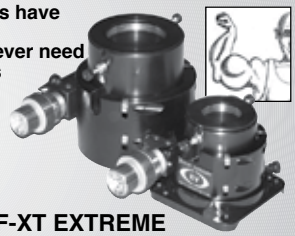

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/// BY ROBERT REEVES

Astronomy thrives in Texas

Texas is a place of legends, cowboys, romance, and astronomy. Here, the sky seems to cover half the world. You can drive 500 miles (800 kilometers) and never encounter a large city. At night, the sky remains so dark, you couldn't count all the stars in a lifetime.

Texans are proud of their night sky and love to share it with others. Dallas has more planetaria per capita than any place on Earth. McDonald Observatory in west Texas boasts the largest telescope in the continental United States — the 362-inch (9.2 meters) Hobby-Eberly Telescope.

From McDonald Observatory to Houston, 600 miles (960 km) to the east, new facilities have evolved to promote public outreach in astronomy education. Not since the dawn of the Space Age has there been such a push to promote astronomy education. These facilities are open to the public, and tourists consider many as destinations.

Comanche Springs Astronomy Campus

About 175 miles (280 km) west of Dallas, there's a new astronomy sheriff in town: the Comanche Springs Astronomy Campus, near Crowell, Texas. Located on the flat plains of the Texas Panhandle, this area has reliably clear weather. The 50-acre astronomy complex is part of the Three Rivers Foundation for the Arts and Sciences. The campus includes observatories, telescopes, a classroom, and areas reserved for camping, observing, and recreational vehicles. Incorporated in 2004, Three Rivers has dedicated thousands of dollars to fund an astronomy campus in Crowell.

The campus' centerpiece is a 15-inch refractor housed in a 28-foot (8.5 meters) dome with an adjacent 30-person classroom. Other facilities include a 40-by-60-foot (12 by 18 meters) roll-off-roof observatory with a 30-inch reflector, a smaller outbuilding with a one-of-a-kind 22-inch binocular telescope, one 10-foot (3m) dome, two 15-foot (4.5m) domes, and the Star Field — an area with 12 light-shielded, electrified concrete observing pads.

Comanche Springs Astronomy Campus features free public star parties monthly on the Saturday nearest the New Moon. Visitors are always welcome to bring their own telescopes. The Three Rivers staff creates special, customized programs for schools and public groups. Daytime activities and weeknight programs require an appointment.

Three Rivers' teacher workshops have trained more than 300 teachers since their inception 4 years ago. The staff uses classroom demonstrations to train teachers how to engage students with educational materials supplied by NASA and the Astronomical Society of the Pacific.

The Comanche Springs Astronomy Campus also maintains the StarsTruck

DOUBLE VISION is a good thing at Comanche Springs Astronomy Campus. Jay Ballauer adjusts the dual eyepieces on the facility's unique 22-inch binocular telescope. BERT STEWART/THREE RIVERS FOUNDATION

COMANCHE SPRINGS Astronomy Campus near Crowell, Texas, appears as a dome on the range. This facility includes a 15-inch refractor housed inside a 28-foot (8.5m) dome, a 30-seat classroom, and smaller domes for other telescopes. BERT STEWART/THREE RIVERS FOUNDATION

A MIGHTY SCOPE, the 15-inch refractor at Comanche Springs Astronomy Campus is the largest public-access telescope of its kind in Texas. BERT STEWART/THREE RIVERS FOUNDATION

MERCURY CROSSED the Sun's disk November 8, 2006. A transit happens when a smaller object passes in front of a larger, background object. Students from Reagan Elementary School in Crowell, Texas, watched the Mercury transit using instruments from the Three Rivers Foundation. LOUIS SANTANA/THREE RIVERS FOUNDATION

mobile astronomy-outreach unit. This 18-foot-long (5.5m) trailer contains telescopes and demonstration gear. When school or public groups request this service, StarsTruck travels up to 200 miles (320 km) from its base in Crowell to perform star parties and lectures. The charge? The hosting organization must provide meals for the StarsTruck team.

Turner Research Station

The Central Texas Astronomical Society (CTAS) operates the Turner Research Station near Clifton, Texas, about 11 miles (18 km) west of Waco. This station's centerpiece is a fully robotic, 2-ton, 24-inch Ritchey-Chrétien reflector, housed in the Paul and Jane Meyer Observatory. Authorized students and researchers anywhere can access the scope via the Internet. The professional-grade instrument has a photometer and a suite of cameras. Using the Turner Research Station as its anchor, CTAS also conducts star parties and workshops for schools and other public organizations.

CTAS makes the 24-inch scope available to students 45 percent of the time and allocates 35 percent of telescope time to original research. Public outreach makes up the remaining 20 percent. The 2-foot-

MEYER OBSERVATORY, located west of Waco, Texas, boasts a 35-foot-tall (10.6m) dome with a 24-inch telescope inside.
JOHN McANALLY/CENTRAL TEXAS ASTRONOMICAL SOCIETY

SCIENCE TEACHERS from Texas Educational Region 12 learn about the Meyer Observatory 24-inch telescope and how they might use it in their classwork.
JOHN McANALLY/CENTRAL TEXAS ASTRONOMICAL SOCIETY

THE 24-INCH SCOPE at Meyer Observatory is a Ritchey-Chrétien research-grade instrument available to professional astronomers and students alike. JOHN McANALLY/CENTRAL TEXAS ASTRONOMICAL SOCIETY

wide (0.6m) telescope resolves celestial objects as faint as 21st magnitude. University of Texas (UT) astronomers use the instrument to supplement research performed at McDonald Observatory.

Scobee Planetarium

In San Antonio, San Antonio College has operated Scobee Planetarium as a public observatory at its downtown campus for 30 years. In spite of the observatory's location, its 10-inch refractor offers unexpectedly steady lunar and planetary views.

Scobee Planetarium offers public shows every Friday evening, followed by public viewing through the college observatory's telescope, manufactured by D&G Optical of Manheim, Pennsylvania. About 20,000 people visit the facility each year. Visitors can enjoy breathtaking views of the Moon and planets. Scobee features three planetarium shows containing educational or popular content daily, Monday through Thursday. College faculty members also teach student astronomy labs there.

Robert Reeves *is an astrophotographer and author who lives in San Antonio. His latest book is* Introduction to Digital Astrophotography, *published by Willmann-Bell in 2005.*

SCOBEE PLANETARIUM Director Bryan Snow proudly shows off the San Antonio College Observatory's new 10-inch refractor. The instrument is available for public viewing each Friday evening after the planetarium show. ROBERT REEVES

George Observatory

Located in Brazos Bend State Park, about 40 miles (60 km) southwest of Houston, George Observatory is a satellite facility of the Houston Museum of Natural Science. The facility's 36-inch Gueymard Research Telescope is the largest public telescope in Texas. Louisiana State University was the scope's previous home, during the Apollo era of the early Space Age. The Houston Museum of Natural Science acquired this massive, 3-foot-wide (0.9m) Ritchey-Chrétien telescope in 1989 and moved it to its current location.

Volunteers from the Houston Astronomical Society and the Ft. Bend Astronomical Society refurbished the telescope. A 35-foot (11m) dome houses the large scope. Experienced telescope-building machinists who helped overhaul the instrument say that, although massive, it is built like a fine watch.

George Observatory is open to the public every Saturday and is available on Fridays by reservation for groups of 30 or more. Other programs include Thursday telescope observing for home-schooled students and college credit for adults pursuing continuing education.

McDonald Observatory

McDonald Observatory near Fort Davis, Texas, is a research observatory located at an elevation of 6,800 feet (2,000m) in the Davis Mountains. Run by the University of Texas at Austin, the facility also serves the public through the Texas Astronomy Education Center, located at the Frank N. Bash Visitors Center. The center lies in the valley between McDonald's 107-inch and 300-inch telescopes. Programs offered through the center provide the public a "hands-on" astronomy experience using research-grade observatory instruments.

The original McDonald Observatory visitor's center and public outreach program, started in 1980, accommodated about 20,000 visitors annually. By 1999,

THE 11-INCH Engebretson refractor installed on George Observatory's 36-inch Gueymard Research Telescope offers the public breathtaking views of the Moon and planets. BARBARA WILSON

THE REBECCA GALE Telescope Park at McDonald Observatory's Frank N. Bash Visitors Center allows public access to large telescopes under a dark sky Tuesday, Friday, and Saturday nights. FRANK CIANCIOLO/ McDONALD OBSERVATORY

STAR-PARTY PARTICIPANTS watch the southern Milky Way in Puppis rise above the domes of McDonald Observatory at the Frank N. Bash Visitors Center. A lecturer in the amphitheater uses a bright beam to point out the constellations, while other visitors view through instruments at the center's telescope park.

FRANK CIANCIOLO/McDONALD OBSERVATORY

130,000 people made the trek to west Texas to experience astronomy at its finest. The old facility was overwhelmed. Private contributions helped bring a new $7 million facility online in 2001.

The new visitor's center features a 12,000-square-foot (1,100 square meters), handicap-accessible building with a 90-seat indoor multimedia theater, an ongoing exhibit titled "Decoding Starlight," which details the stellar spectroscopic research done with the 107-inch and 300-inch telescopes at McDonald Observatory, and dining facilities.

The Rebecca Gale Telescope Park lies next to the visitor's center and houses a 22-inch Newtonian scope, a 16-inch Schmidt-Cassegrain reflector, an 8-inch telescope with fixed-position eyepiece for handicap access, and numerous smaller portable telescopes.

A popular part of evening programs at McDonald is the sky tour conducted by an experienced lecturer at the 350-seat outdoor amphitheater.

The Texas Astronomy Education Center offers teacher workshops. These popular sessions attract attendees from as far away as Alaska. Teachers can earn up to 20 hours of continuing-education credits while working with state-of-the-art astronomical instruments.

Video conferencing allows the staff at the Texas Astronomy Education Center to interact with thousands of students across Texas with live presentations fed to their classrooms. Presentations route through the Connect With Texas Program through the state's regional educational service centers. During a recent Astronomy Day hookup, 10,000 students participated in live solar observing originating from McDonald Observatory.

The combination of impressive facilities open to the public and dark skies for good seeing makes Texas an outstanding destination for astronomers. Observers definitely see Texas as much more than a "lone star" state.

/// CONTACT INFORMATION

LEARN MORE ABOUT TEXAS ASTRONOMY

Comanche Springs Astronomy Campus
Off U.S. Highway 70, about 15 miles (24 km) west of Crowell, Texas
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[w] www.3rf.org
- Public star party each Saturday closest to the New Moon.
- Public viewing with the 15-inch refractor Friday and Saturday nights in the summer.
- Teacher continuing-education workshops.
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Central Texas Astronomical Society Turner Research Station
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[w] www.centexastronomy.org
- Public star parties.
- Teacher workshops.
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- Professional research.

Scobee Planetarium
San Antonio College campus
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San Antonio, Texas
[t] 210.733.2910
[w] www.accd.edu/sac/ce/scobee
- Public observing Friday evenings after planetarium shows.

George Observatory
Located in Brazos Bend State Park, 40 miles (64 km) southwest of Houston
[t] 218.242.3055 or 979.553.3400
[w] www.hmns.org/see_do/george_observatory.asp
- Student observing Thursday evenings.
- Private observing Friday evenings for groups of 30 or more.
- Public observing Saturday evenings.
- Class for kindergarten through eighth-grade students.

McDonald Observatory
Off Texas Highway 118, 16 miles (26 km) west of Ft. Davis, Texas
[t] 432.426.3640
[w] mcdonaldobservatory.org/visitors
- Frank N. Bash Visitors Center is open daily between 10 A.M. and 5:30 P.M.
- Daily 90-minute guided observatory tours and solar observing at 11 A.M. and 2 P.M.
- Public observing Tuesday, Friday, and Saturday nights.
- Special 5-hour dinner and observing program several nights per month with the 82-inch Struve reflector.
- Special program using the 107-inch Harlan Smith reflector one night per month near the Full Moon.
- Teacher continuing-education workshops.
- Student field trips.

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Sharp optics in two beautiful packages make these telescopes easy to look at and easier to look through. /// **BY RAYMOND SHUBINSKI**

Sky-testing William Optics' new refractors

First impressions last. I know you shouldn't judge books by their covers, but the William Optics Megrez 90mm apochromatic refractor (APO) and the ZenithStar 66SD APO exude quality. Even the swan logo provides an extra touch of class. The new breed of light-weight and short-focal-length telescopes is a far cry from refractors of the mid-20th century and earlier. Today's urban amateur who needs a quick "observing fix" will find this pair of scopes from William Optics just the tools for backyard browsing or traveling. These instruments are so compact, you can put them in your Mini Cooper and be off to your favorite dark site in no time.

Two gorgeous scopes

Both telescopes come in well-constructed (high-impact) aluminum and plastic cases with protective foam linings. The Megrez 90 has a white barrel with an oversized, extendable dew cap. William Optics anodized the back end of the dew cap in gold, which adds to this instrument's overall visual impact. Even the lens cap is gold-anodized. Where the tube joins the focuser, a gold ring completes the look.

The focusing knobs are oversized and easy to use even while wearing gloves. The focuser has two knobs, one for coarse focus and a smaller brass knob that extends off the large knob for fine focus. A calibration scale on the focusing tube adds extra value.

The Megrez 90 holds a 2" star diagonal. William Optics supplies a dielectric coated version with carbon-fiber side panels. The carbon fiber adds to the look (and reduces the weight a bit), and the dielectric coating provides a bright image.

The ZenithStar 66SD shares many of the same features as the Megrez 90. The ZenithStar's tube is orange. It has the same focuser as the Megrez 90 and accommodates a 1¼" star diagonal (a 2" adapter is available). Even the focusing tube has the same scale. The two-speed focuser simplifies focusing on the ZenithStar. Neither scope comes with a finder, but this was not a problem in using them.

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William Optics
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HIGH-IMPACT aluminum and plastic cases with foam linings come with both telescopes. Both cases will fit in most airline carry-on compartments.

Observing the Moon

I first pointed the Megrez 90 at the Moon. Because these telescopes came without mounts, I put the Megrez 90 on another manufacturer's lightweight mount. Topping out at just over 7 pounds (3.2 kg), the scope remained stable even with the 2" star diagonal and large eyepieces installed.

The ZenithStar 66SD accommodates a 1¼" star diagonal, but can be ordered with a 2" adapter. The ZenithStar fit well on a heavy-duty camera tripod, but sagged a bit when I inserted heavier eyepieces.

Now that I was set, I started with a 4-day-old Moon. Through the Megrez 90, with a 30mm eyepiece (21x), the thin crescent floated beautifully in the scope's

WILLIAM OPTICS' **Megrez 90 (top) and ZenithStar 66SD refractors make great travel scopes. With their dew caps retracted, they measure 16.9" (430mm) and 11.8" (300mm), respectively.** ALL PHOTOS: *ASTRONOMY*: JAMES FORBES; BACKGROUND IMAGES: ADAM BLOCK/NOAO/AURA/NSF

wide field of view. Because these scopes have short focal lengths, you'll have to use short-focal-length eyepieces to increase the magnification to see fine detail.

At low power, Mare Crisium stood out as a stark black "sea," while above it I could make out Mare Fecunditatis. I increased the power with a 13mm eyepiece (48x), and the two dark, well-defined craters near Mare Crisium's western edge were easy targets. Just north of Crisium, the large crater Cleomedes appeared nicely defined, as were a wealth of other details. Even through a 3mm eyepiece (207x), the lunar terminator came alive with detail.

A wonderful feature of these Williams Optics telescopes is the 360° rotatable focuser. How many times have you been observing when the eyepiece got into an awkward position? This is not a problem with this telescope line. A single set screw allows the entire focusing assembly to rotate. No more stiff necks!

Making the same observations with the ZenithStar 66SD, objects appeared fainter, which I expected considering the smaller aperture. The scope performed well, although the 3mm eyepiece (129x) was a bit much for the smaller scope, at least under that evening's sky conditions.

Into the deep sky

In early spring before the time change, I turned the telescopes to the Orion Nebula (M42) and a few other sights. Through the 20mm eyepiece, the overall brightness of M42 and the way it filled the field of view impressed me. The bright nebula's dark center was easy to follow, and its outer filaments were easy to trace.

Placing the same eyepiece in the ZenithStar 66SD, the image was no less pleasing, although the outer filaments were more difficult to see. Next, I dropped the 13mm eyepiece back into the Megrez 90 and could easily make out the Trapezium's four stars. I also could see the Trapezium through the ZenithStar, but, as expected, with diminished brightness.

Although Rigel (Beta [β] Orionis) was getting low, I tried to split that double star. Through the Megrez 90 and the 3mm

ONE ACCESSORY **worth having is William Optics' dielectric-coated 2" star diagonal. Carbon-fiber side panels add to the look of the diagonal, and the dielectric coating provides a bright image.**

Raymond Shubinski *is a long-time refractor lover who observes from Kansas City, Missouri.*

eyepiece, I could make out the magnitude 7 companion with some effort. I suspect this was due more to Rigel's low altitude than the telescope. I could not split Rigel through the ZenithStar 66SD.

The telescopes' flat, wide fields of view produced outstanding images to the edge of the field. At one point, I equipped the Megrez 90 with the 13mm eyepiece and let the Orion Nebula drift across the field of view. The image was crisp from the moment it appeared until it disappeared.

I turned both telescopes on Denebola (Beta Leonis) to test their optics. This star shines at magnitude 2.14, so it makes a good candidate for this test. If you view a star using high magnification, and defocus the image, you will see a series of concentric rings. Both the Megrez 90 and the ZenithStar 66SD showed perfect sets of rings on both sides of focus.

Many amateurs delight in testing their refractors by hunting double stars. One of the finest is Gamma (γ) Leonis. Both telescopes easily split this object at low magnification. With an angular separation of 4", this double star is easy to split. What impressed me was the dark sky between the two stars. This clearly showed the outstanding resolution and contrast provided by both scopes' optics.

Next, I moved to the Praesepe or Beehive Cluster (M44) in Cancer. This open star cluster was a stunner through both telescopes at low power. Because of the outstanding contrast, the Beehive's bright stars appeared almost three-dimensional against a dark background.

I also observed Saturn as it reappeared in the spring sky. The ZenithStar 66SD showed Saturn as a small disk through a 22mm eyepiece (18x). As I increased the magnification, the rings began to resolve. The image, however, remained fairly small. The same situation occurred with the Megrez 90, but the rings resolved more quickly through the 13mm eyepiece. As I pushed the limit with the 3mm eyepiece, the image held up well, and the outstanding contrast added to its quality.

A winning pair

William Optics' ZenithStar 66SD and Megrez 90 are outstanding products at reasonable prices. With either of these fine scopes, almost any backyard astronomer can enjoy the pleasures of a classic refractor with 21st-century refinements.

A CRAYFORD two-speed microfocuser makes focusing easy. The knobs are oversized and easy to use even when wearing gloves. The focuser rotates 360° and locks into place so you won't find yourself in awkward positions when observing.

THE ZENITHSTAR 66SD also employs a dual-speed, 360° rotatable Crayford focuser. A calibration scale on each tube allows you to return to previous focusing positions. Both focusers employ anti-marring brass compression rings.

/// SPECIFICATIONS

WILLIAM OPTICS ZENITHSTAR 66SD AND MEGREZ 90

	ZenithStar 66SD	Megrez 90
Aperture:	2.4 inches (66mm)	3.5 inches (90mm)
Focal ratio:	f/5.9	f/6.9
Focal length:	388mm	621mm
Tube length: (retracted)	11.8" (300mm)	16.9" (430mm)
Tube weight:	3.5 pounds (1.7 kg)	7 pounds (3.2 kg)
Focuser:	1¼"	2" with 1¼" adapter
Both come with:	Retractable lens shade, 360° rotatable focuser, dual-speed microfocuser, aluminum case	
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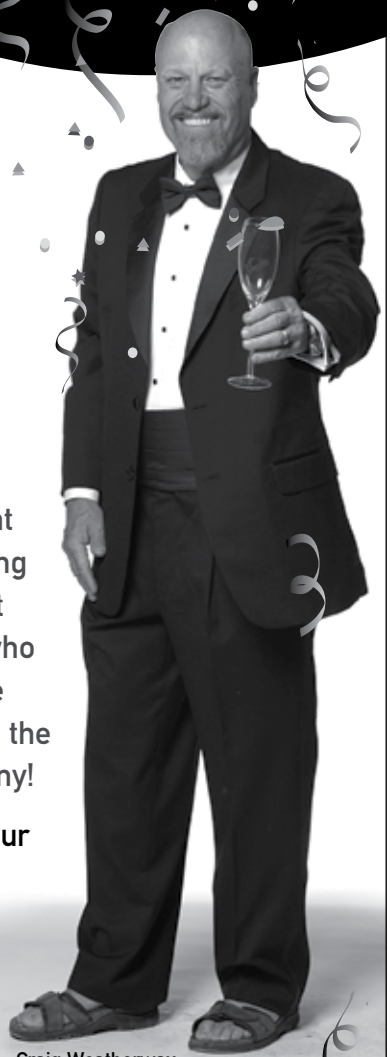

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Choosing the right eyepiece is easy with Meade's Series 5000 oculars. /// **BY MIKE D. REYNOLDS**

Plössls

Experience Meade's new eyepieces

While a good eyepiece is a must, a great eyepiece — one with extraordinary design and exceptional optics — can turn an average evening of astronomical viewing into an unforgettable visual feast. Recently, I put Meade's Series 5000 eyepieces and TeleXtender power multipliers to the test during several observing sessions.

The Series 5000 eyepieces are attractive and appear well-manufactured. The company offers its Series 5000 eyepieces in three design types: Plössl, Super Wide Angle, and Ultra Wide Angle. Plössls include 5- and 6-element designs, while Super Wide Angle and Ultra Wide Angle eyepieces have 6- and 7-element designs. Meade's TeleXtenders, which increase an eyepiece's magnification, have a 4-element design. Each eyepiece-design type has a different color band: Plössls sport a red band, Super Wide Angle eyepieces have a green band, and Ultra Wide Angle eyepieces show a blue band.

A CARRYING CASE comes with all Meade Series 5000 eyepiece packages, including this set of Ultra Wide Angle 1¼" eyepieces. The aluminum, foam-fitted case lets you store or transport your glass. *ASTRONOMY*: WILLIAM ZUBACK

I carefully examined each eyepiece and TeleXtender, checking the optical surfaces for any obvious defects. I found none. Then, I tested all of the eyepieces and TeleXtenders through three different telescopes and on a variety of celestial targets. I used a 3.2-inch f/6 apochromatic refractor, an 8-inch f/10 Schmidt-Cassegrain telescope, and a 10-inch Dobsonian-mounted reflector to observe the First Quarter Moon, Saturn, the Orion Nebula (M42), the Pleiades (M45), magnitude 6.3 globular cluster M3 in Canes Venatici, and several bright and dim stars.

I checked each eyepiece for sharpness, astigmatism, field curvature, ghosting, and the object's color through each of the three telescopes. Subtle color differences are subjective. A more objective test of the optics is the observed amount of field curvature — whether stars at the edge of the field of view are as sharp as stars in the center of the field of view.

Meade incorporates an adjustable, twist-up rubber eyeguard into each eyepiece. Most eyeguards operated smoothly and adjusted easily at the telescope; however, some eyeguards were a bit sticky.

Mike D. Reynolds *is an astronomy professor and associate dean of Mathematics and Natural Sciences at Florida Community College. He has written several astronomy books, including* Falling Stars: A Guide to Meteors & Meteorites *(2001).*

How the Plössls performed

The first eyepieces I tested on each object and through each telescope were the Plössls. For me, each provided excellent eye relief — the distance between the observer's eye and the eyepiece when the observer sees the black circular field stop (the ring inside the eyepiece barrel that limits the eyepiece's apparent field of view). Good eye relief keeps you from having to place your eye right up against the eyepiece. Without sufficient eye relief, eyelash oils and mascara may get on the eyepiece's outer lens and degrade the view.

Images were sharp in the center of the 60° field of view and fairly sharp to the edge of the field. The color appeared good, and I detected no image ghosting.

Sizing up the super wides

The Super Wide Angle eyepieces didn't disappoint in any way. The images were sharp and had excellent color through the eyepieces' 68° fields, and I found no shift in focus point from eyepiece to eyepiece. The Orion Nebula was sharp, and the Pleiades was a delight at low magnifications through the 3.2-inch refractor.

Ultra Wide Angle **Super Wide Angle** **TeleXtenders**

Astounding ultra wides

It's a good thing I didn't test any Series 5000 Ultra Wide Angle eyepieces before I tested the Super Wide Angle or the Plössl eyepieces. Otherwise, I would have never changed eyepieces! Solar system objects viewed at high magnifications — the First Quarter Moon and Saturn — were exquisite. I noted no flaring or ghosting on bright stars like Betelgeuse (Alpha [α] Orionis) and Sirius (Alpha [α] Canis Majoris). The Pleiades and deep-sky objects like the Orion Nebula and M3 were superb.

I spent an extra night using the Super Wide and Ultra Wide Angle eyepieces with my 18-inch f/6 Dobsonian-mounted reflector. I found the views through the longer-focal-length, 82°-field eyepieces outstanding. My first view of M3 with the Ultra Wide Angle 24mm eyepiece was breathtaking — and this is not a word I would normally use to describe M3, although it is one of my Northern Hemisphere deep-sky favorites.

Extending the power

Meade's TeleXtender power multipliers showed no visual deficiencies and worked well with all three eyepiece sets. I especially enjoyed using the 5x TeleXtender to push each telescope to its theoretical limit of 50 magnifications per aperture inch.

Occasionally, I fumble in the dark tightening a lock screw. Fortunately, each TeleXtender has a large, easy-to-find locking screw. This is an advantage if you're wearing gloves. The inner compression rings provide a secure lock and won't mar the eyepiece, diagonal, or camera-mount tube. The 2" Series 5000 TeleXtenders include a 1¼" adapter, also with the oversized lock screw. Overall, I'd rate the TeleXtenders' performance as excellent.

A few things to consider

Eyepieces with 2" barrels require more glass than 1¼" eyepieces. These larger eyepieces are also relatively heavy. The Super Wide Angle 40mm 2" eyepiece weighs 44 ounces (1,368 grams), while the Ultra Wide Angle 30mm 2" tips the scales at a whopping 47 ounces (1,462 grams). Consider counterbalancing heavier eyepieces, especially on small Dobsonian-mounted scopes. I use a lead-filled beanbag as a counterweight.

Great eyepieces can be pricey, but the visual results are well worth the investment. Some observers spend more on an eyepiece than they do on their telescope. Meade priced the Super Wide Angle and Ultra Wide Angle eyepieces competitively compared to other high-end eyepieces.

Meade offers several different Series 5000 eyepiece packages, all of which include an attractive and protective case for your investment. These custom aluminum, foam-fitted cases are excellent for storage. Individual eyepieces arrive in heavy-duty custom-fit cardboard boxes. End caps come with all eyepieces and TeleXtenders to protect the exposed optics from dust while not in use.

Excellent oculars

Meade's Series 5000 Plössl eyepieces offer a solid choice for a first set of eyepieces. And the Super Wide Angle and, especially, the Ultra Wide Angle eyepieces excelled regardless of the object I viewed or the telescope I used. I also found the TeleXtenders good for producing magnifications not offered by the three eyepiece sets.

MEADE'S 5000 SERIES offers a range of outstanding eyepieces. Choose the apparent field of view that best suits your observing needs: The Plössls provide a 60° field, the Super Wide Angles boast a 68° field, and the Ultra Wide Angles give an astounding 82°. *ASTRONOMY:* WILLIAM ZUBACK

MEADE SERIES 5000 EYEPIECES REVIEWED

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Ultra Wide Angle; blue band

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6.7mm 1¼" ($199)
8.8mm 1¼" ($199)
14mm 1¼" ($199)
18mm 1¼" ($279)
24mm 2" ($399)
30mm 2" ($449)

Super Wide Angle; green band

16mm 1¼" ($179)
20mm 1¼" ($199)
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28mm 2" ($279)
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TeleXtenders; 4-element

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2x 2" with a 1¼" adapter ($159)
3x 1¼" ($159)
5x 1¼" ($229)

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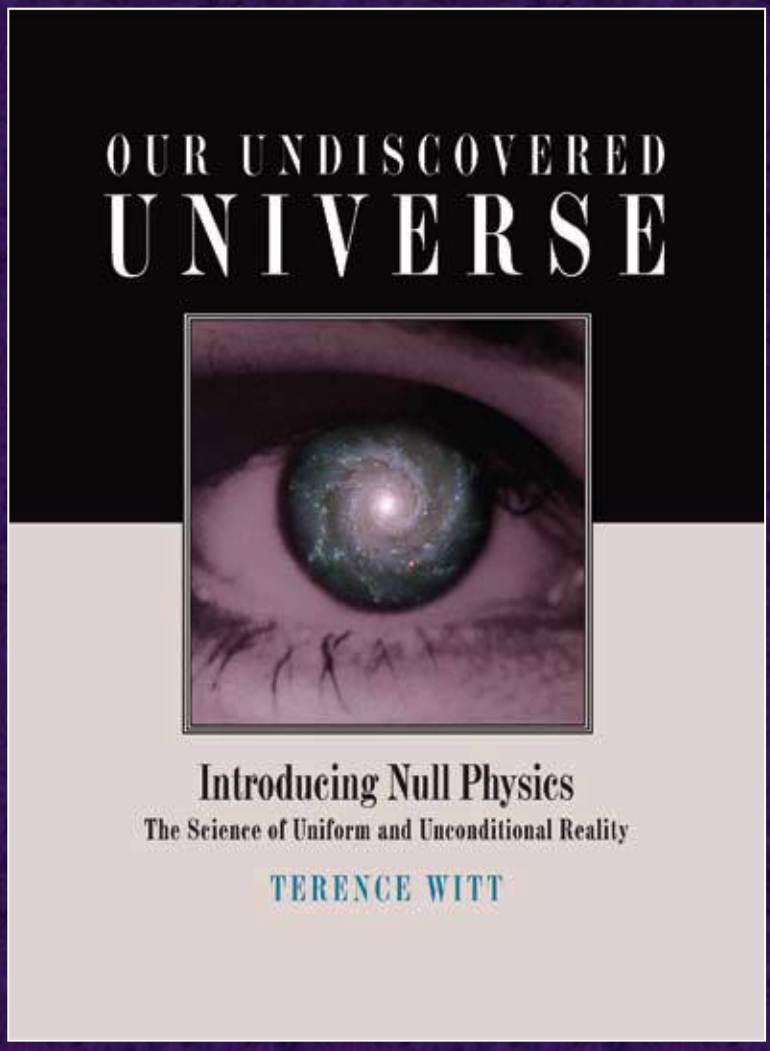

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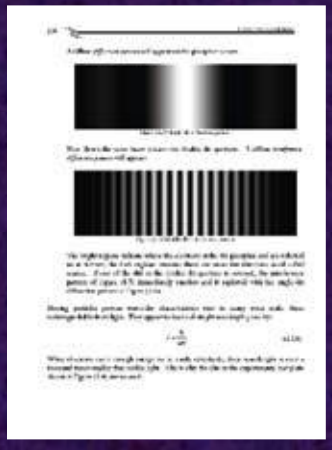

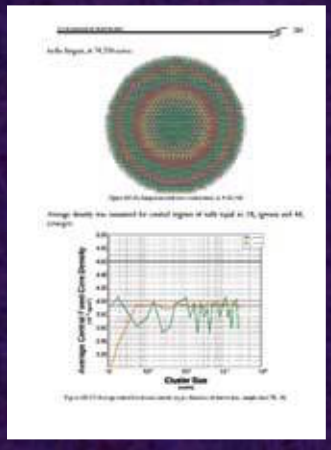

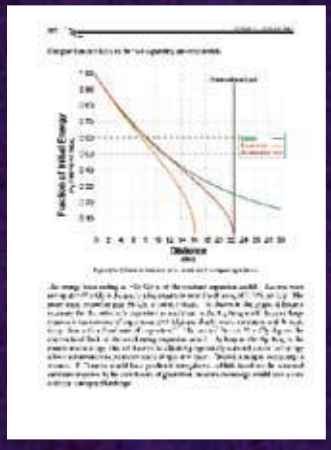

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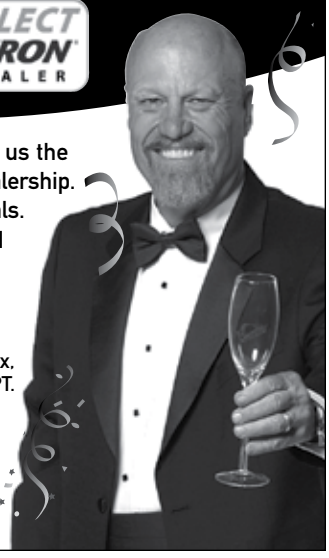

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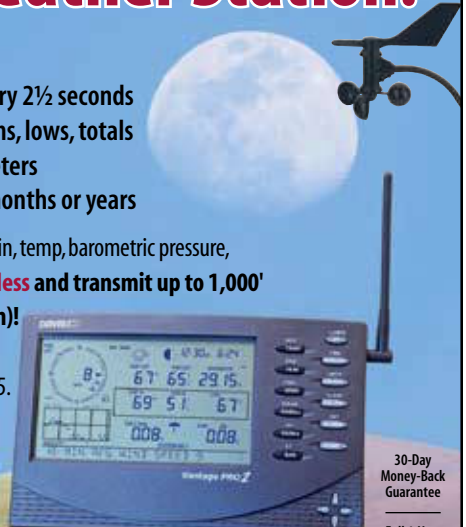

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Observe a dark sky from the dunes

Hosted by the New Mexico Museum

of Space History, White Sands National Monument, and Alamogordo Astronomy Club, the White Sands Star Party near Alamogordo, New Mexico, offers a chance to stargaze from one of the United States' premier protected locations.

WHITE SANDS STAR PARTY visitors will have special access to explore the monument's rolling dunes. Participants can share their telescopes Saturday, October 5, for public observing from dusk until 11 P.M. IAN PARKER

Besides stargazing from the sand dunes, participants will have access to keynote speakers, camping privileges, an IMAX theater, workshops, and tours.

Proceeds help support Project ASTRO-New Mexico. The program provides classrooms with astronomers to help teach the subject.

☎ Leah Tookey at 505.437.2840, ext. 41136; 💻 www.zianet.com/wssp.

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Whirlpool Star Party
Dooly's Hotel, Birr, Co. Offaly, Ireland.
💻 www.shannonsideastronomy.com.

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Bays Mountain StarFest
Bays Mountain Park and Planetarium, Kingsport, Tennessee. ☎ 423.229.9447; 💻 www.baysmountain.com/planetdept/astronomy.html.

OCTOBER 6–14
Okie-Tex Star Party
Camp Billy Joe, Kenton, Oklahoma.
✉ starpartyinfo@okie-tex.com; 💻 www.okie-tex.com.

OCTOBER 7–14
Peach State Star Gaze
Deerlick Astronomy Village, near Sharon,

Georgia. ✉ PSSG@atlantaastronomy.org; 💻 www.atlantaastronomy.org/PSSG.

OCTOBER 10–13
Eldorado Star Party
X-Bar Ranch, near Eldorado, Texas. 💻 www.texasstarparty.org/eldorado.html.

OCTOBER 12–13
All-Arizona Star Party
Farnsworth Ranch, near Arizona City, Arizona. ✉ president@eastvalleyastronomy.org; 💻 www.eastvalleyastronomy.org/aasp.htm.

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Death Valley/Las Vegas Astronomical Society Star Party
Death Valley National Park and Furnace Creek Resort, Death Valley, California. 💻 www.furnacecreekresort.com.

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Hidden Hollow Star Party
Warren Rupp Observatory, Mansfield, Ohio. ✉ theastronomer@webtv.net; 💻 www.wro.org/hiddenhollow07.html.

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Jersey Starquest
Hope Conference Center, Hope, New Jersey. ☎ Don Monticello at 609.882.1257; ✉ dmonticello@hotmail.com; 💻 www.princetonastronomy.org.

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OCTOBER 19–20
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Custer Institute and Observatory, Southold, New York. 💻 www.custerobservatory.org. A

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Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or edolan@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

INDEX *of* ADVERTISERS

20-20 Telescopes 82
Adirondack Video Astronomy 82
Adorama 7, 15
Agena Astro Products 82
Anacortes Telescope & Wild Bird 85
AP Theory 64
Aridian Publishing 77
Ash Manufacturing 82
Astro Gizmos 85
Astro-Physics 84
AstroMart.com 83
Astronomics 13
Astronomy.com 79, 85
Astronomy Delight 83
Astronomy magazine 73, 76, 80
Astronomy magazine's Iceland 2008 Tour 76
Astronomy Technologies 7
Astrozap 64
Atomic Time 11
Beam of Light Technologies 83
Beta Electronics 81
Bethany Sciences 81
Big Bang Astronomy Shop 81
Binoculars.com 81
Celestron 90
Davis Instruments 79
Denkmeier Optical 81
Durango Skies 83
Efstonscience, Inc 64, 82
Enchanted Skies Star Party 56
Equatorial Platforms 83
Farpoint Astronomical Research 83
Flo USA, Inc 82
Focus Camera 64, 85
Glatter Howard 83
Hubble's Greatest Pictures 56
Jim's Mobile, Inc 64
Khan Scope Centre 81
Kitt Peak National Observatory 11
Knightware 84
Let's Talk Stars 64
Luckyduck.com 82, 85
Lumicon 18
Meade Instruments Corporation 2, 3
Mithec-Delamere Publishers 83
Moonlite Telescope Accessories 83
Oceanside Photo & Telescope 73, 79
Orb Publishing 84
Orion Telescopes & Binoculars 57
Owl Services 64
Pegasus Optics 84
Preserve at Little Pine Observatory 18
Rainbow Symphony 85
Ritz Camera Superstores 82
Royal Cruise Adventures 84
Sahara Sky 85
Santa Barbara Instrument Group 89
Scientific American Book Club 43
Scope Buggy 84
Scope City 11
Scoperoller.com 84
ScopeStuff 83
SCS Astro 85
Seymour Solar 83
Shutan Camera & Video 64
Smartastronomy.com 83
Software Bisque, Inc 22, 23
Solarscope 83
Southeastern Camera & Telescope 81
Stargazers Inn 81
StarGPS 84
Stellarvue 85
Technical Innovations 79
Tele Vue Optics, Inc 9
Telegizmos 84
The Teaching Company 19
University Optics, Inc 84
Vixen Optics 64
Wicked Lasers 65, 81
William Optics Co 76
Woodland Hills Camera & Telescopes 56
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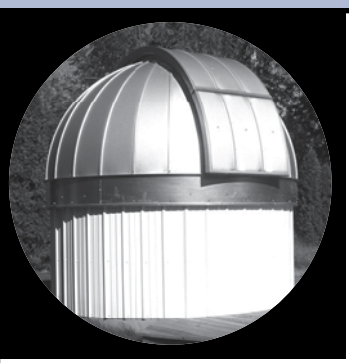

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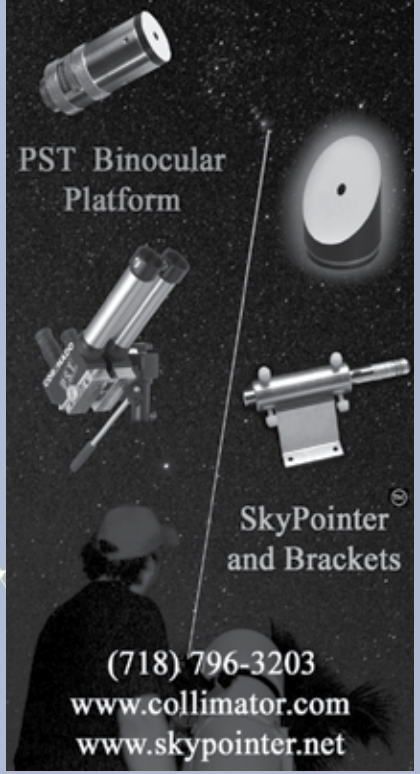

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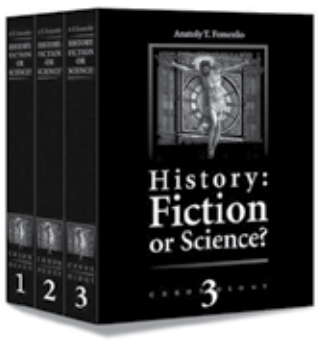

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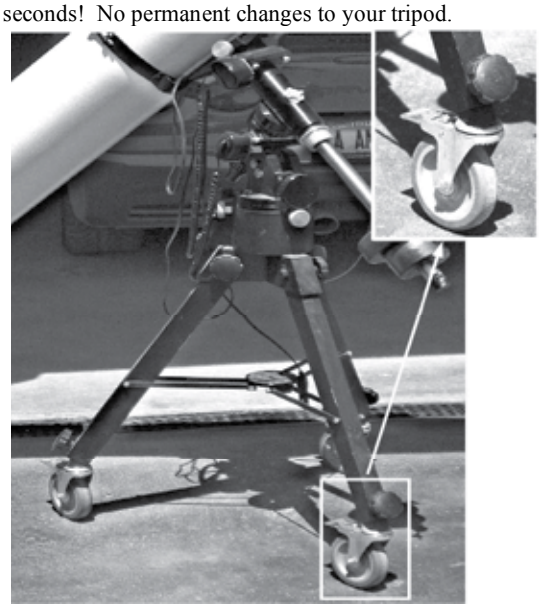

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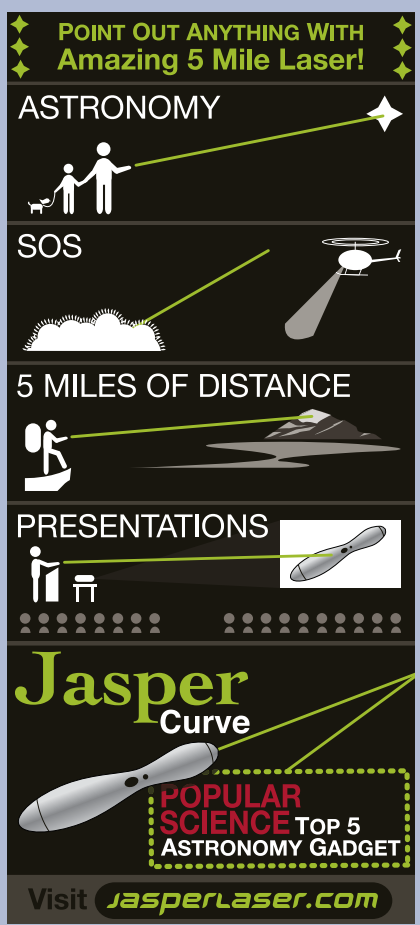

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NGC 2403 shines at magnitude 8.2 and measures 23' by 12'. It lies 10 million light-years away, just past the Local Group, the collection of about 40 galaxies that contains the Milky Way and the Andromeda Galaxy (M31). The reddish regions in this image are glowing hydrogen clouds. Blue areas represent recently formed star clusters.

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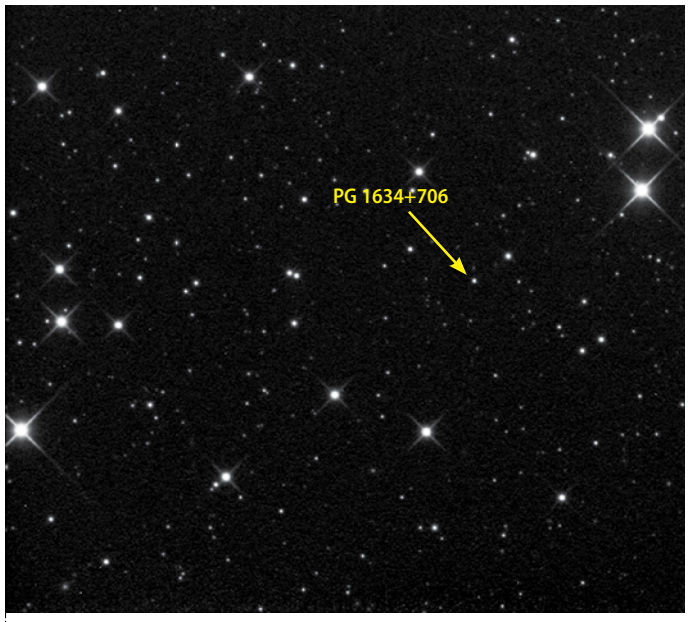
3C 273 IN VIRGO was one of the first quasars discovered. Astronomers found the radio source and identified an optical counterpart in 1963. At magnitude 12.7, it's the brightest quasar. (6.4-inch Astro-Physics 160 Starfire EDF apochromatic refractor at f/7.5, SBIG ST-2000XM CCD camera, combination of five 6-minute unfiltered exposures) /// **ANTHONY AYIOMAMITIS, ATHENS, GREECE**



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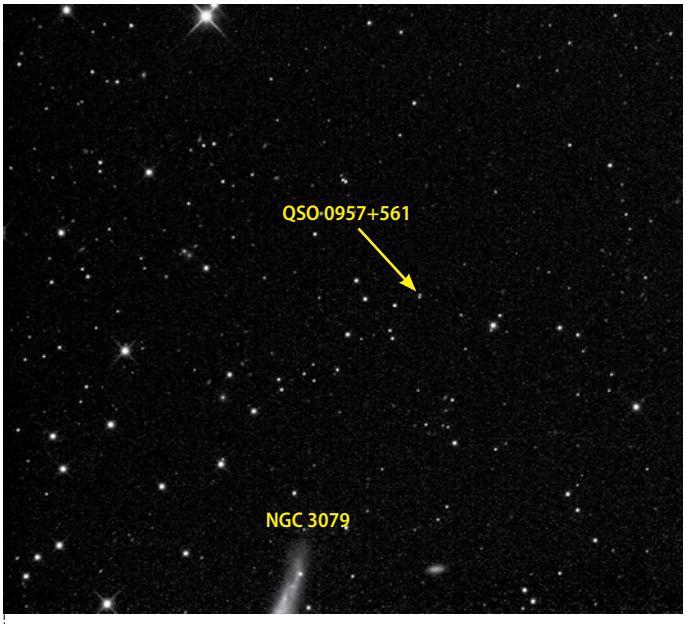
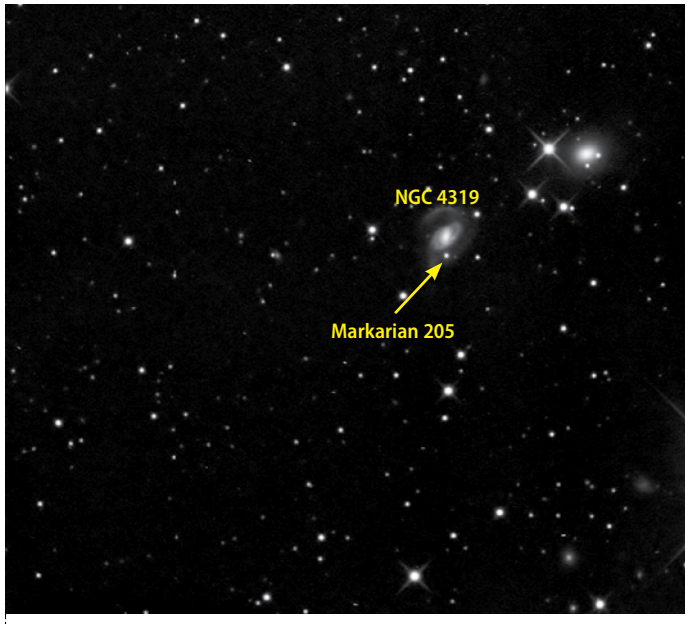


THE TWIN QUASAR QSO 0957+561 in Ursa Major is one object split into two images by an unseen mass between it and Earth. In 1979, QSO 0957+561 became the first gravitationally lensed object identified. It lies 7.8 billion light-years away. (6.4-inch Astro-Physics 160 Starfire EDF apochromatic refractor at f/7.5, SBIG ST-2000XM CCD camera, combination of fifteen 3-minute unfiltered exposures) /// **ANTHONY AYIOMAMITIS, ATHENS, GREECE**



MARKARIAN 205 in Draco, a magnitude 15.2 quasar, lies positioned near spiral galaxy NGC 4319. The two objects, however, are unrelated. NGC 4319 lies 105 million light-years away, while Markarian 205 lies 1.2 billion light-years distant. (6.4-inch Astro-Physics 160 Starfire EDF apochromatic refractor at f/7.5, SBIG ST-2000XM CCD camera, combination of five 6-minute unfiltered exposures) /// **ANTHONY AYIOMAMITIS, ATHENS, GREECE**

CYGNUS THE SWAN CONTAINS MANY WONDERFUL OBJECTS for amateur telescopes. This image shows the region surrounding Deneb (Alpha [α] Cygni) and Sadr (Gamma [γ] Cygni). (35mm Mamiya film camera, 250mm Mamiya lens at f/6.2, Kodak Ektachrome 200 film pushed to ISO 400, 60-minute exposure) /// **DANILO PIVATO, ROME**

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This beautiful mosaic of Rho Ophiuchus was taken remotely using an SBIG STL-11000M camera and Takahashi FSQ106 refractor in a joint effort by three advanced amateurs. Jim Misti took the two hour image using Steve Mazlin's refractor, and the image data was processed by Robert Gendler.

SANTA BARBARA INSTRUMENT GROUP
147-A Castilian Drive
Santa Barbara, CA 93117
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